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ROTARY SWAGED RAPID-FIRE GUN BARRELS

D. C. Drennen, et al

Battelle Memorial Institute

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August 1972

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TECHNICAL REPORT

D. C. Drennen, Dr. C. M. Jackson
Battelle Memorial Institute
and
R. B. Miclot, Dr. K. R. Iyer
USAWECOM

RESEARCH DIRECTORATE

WEAPONS LABORATORY USAWECOM

RESEARCH, DEVELOPMENT AND ENGINEERING DIRECTORATE

U. S. ARMY WEAPONS COMMAND

87

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13 ABSTRACT

A program was undertaken by the Research Directorate, Weapons Laboratory USAWECOM, to investigate the feasibility of forming 7.62mm rifled gun barrels from three high-temperature alloys and a stainless steel by swaging. The high-temperature superalloys selected for evaluation were Inconel 718, Udimet 700, and Crucible CG-27, whereas the stainless steel was Armco 21-6-9. Gun barrel blanks of each alloy were prepared by gun drilling. Twenty-two rifled 7.62mm gun barrel blanks of the four selected materials were formed by swaging without any insolvable problems. Evaluation of the as-swaged blanks revealed that high quality gun barrels can be formed from each of these alloys. Further analyses, conducted on short samples of the swaged barrel blanks, showed that the age-hardenable alloys can be heat treated without destroying the bore configuration. As-swaged barrel blanks of Inconel 718 and Udimet 700 were heat treated and 7.62mm M60 barrels were fabricated from these blanks. These completed barrels and the nonheat-treatable Armco 21-6-9 were test fired, metallurgically analyzed, and their performance characteristics were documented. The performance characteristics of Crucible CG-27, as a rapid-fire small caliber gun barrel, will be presented in a separate technical report. (U) (Drennen, D.C., Jackson, C.M., Miclot, R.B., and Iyer, K. R.)

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Details of illustrations in this document may be better studied on microfiche

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ABSTRACT

A program was undertaken by the Research Directorate, Weapons Laboratory USAWECOM, to investigate the feasibility of forming 7.62mm rifled gun barrels from three high-temperature alloys and a stainless steel by swaging. The high-temperature superalloys selected for evaluation were Inconel 718, Udimet 700, and Crucible CG-27, whereas the stainless steel was Armco 21-6-9.

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As-swaged barrel blanks of Inconel 718 and Udimet 700 were heat treated and 7.62mm M60 barrels were fabricated from these blanks. These completed barrels and the nonheat-treatable Armco 21-6-9 were test fired, metallurgically analyzed, and their performance characteristics were documented. The performance characteristics of Crucible CG-27, as a rapid-fire small caliber gun barrel, will be presented in a separate technical report.

FOREWORD

The swaging studies and swaging of blanks made of superalloys for this program were performed by Battelle Memorial Institute, Columbus, Ohio, under Contract DAAF03-70-C-0005. The contract supervisor was R. B. Miclot. The test firings of the rotary-swaged barrels and the test-firing analysis were conducted by R. B. Miclot and Dr. K. R. Iyer of the Research Directorate, Weapons Laboratory USAWECOM.

CONTENTS

CONTENTS

TABULAR DATA

ILLUSTRATIONS

ILLUSTRATIONS

ILLUSTRATIONS

INTRODUCTION

Currently, U.S. small-arms gun barrels are produced from Cr-Mo-V low alloy steels with nominally 0.48 per cent carbon, heat treated to a hardness of Rockwell C 32-34. The bore is chromium plated, and may contain a liner of Stellite 21 in the breech end.

The Research Directorate of the Weapons Laboratory USAWECOM is concerned with the improvement of the performance of small-arms gun barrel materials. Therefore, a program was undertaken with the Columbus Laboratories of Battelle Memorial Institute to study procedures suitable for manufacturing gun barrels from high-strength materials. Specifically, the objective of this program is to investigate the feasibility of forming rifled gun barrels from the following three high-temperature alloys and a stainless steel by swaging techniques:

Alloy	Alloy Base
Inconel Alloy 718	Nickel
Udimet Alloy U 700	Nickel
Crucible Alloy CG-27	Iron
Armco Alloy 21-6-9	Iron

The barrel to be formed is a 7.62mm gun barrel and the interior configuration is shown in Figure 1.

The typical short-time, high-temperature yield strengths of the alloys selected for evaluation as gun barrel materials are shown in Figure 2. The principal objection to using materials such as these for gun barrels, aside from the inherently higher cost than that of alloy steel, is that their machinability and formability are relatively low. Consequently, the applicability of the rotary swage to the rifling of gun barrel bores to offset cost disadvantages was investigated.

LITERATURE SEARCH AND FIELD SURVEY

The technical literature concerning the internal swaging of gun barrels was examined. A very limited amount of information was found on (1) the design of, and materials for, dies and mandrels, (2) the starting blank configuration, (3) reductions in area required, (4) feeding methods for the workpiece, and (5) lubricants used during the forming operation.

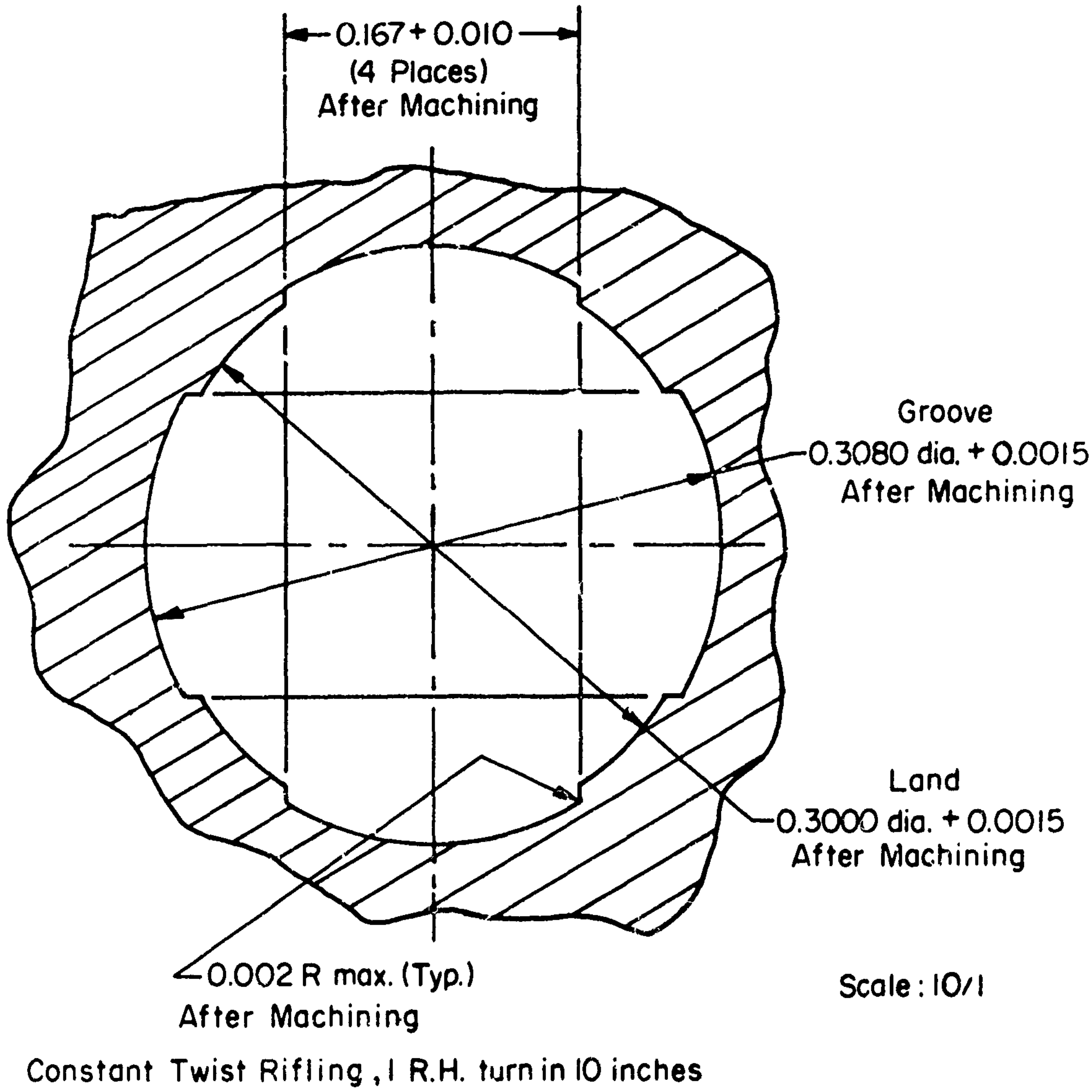
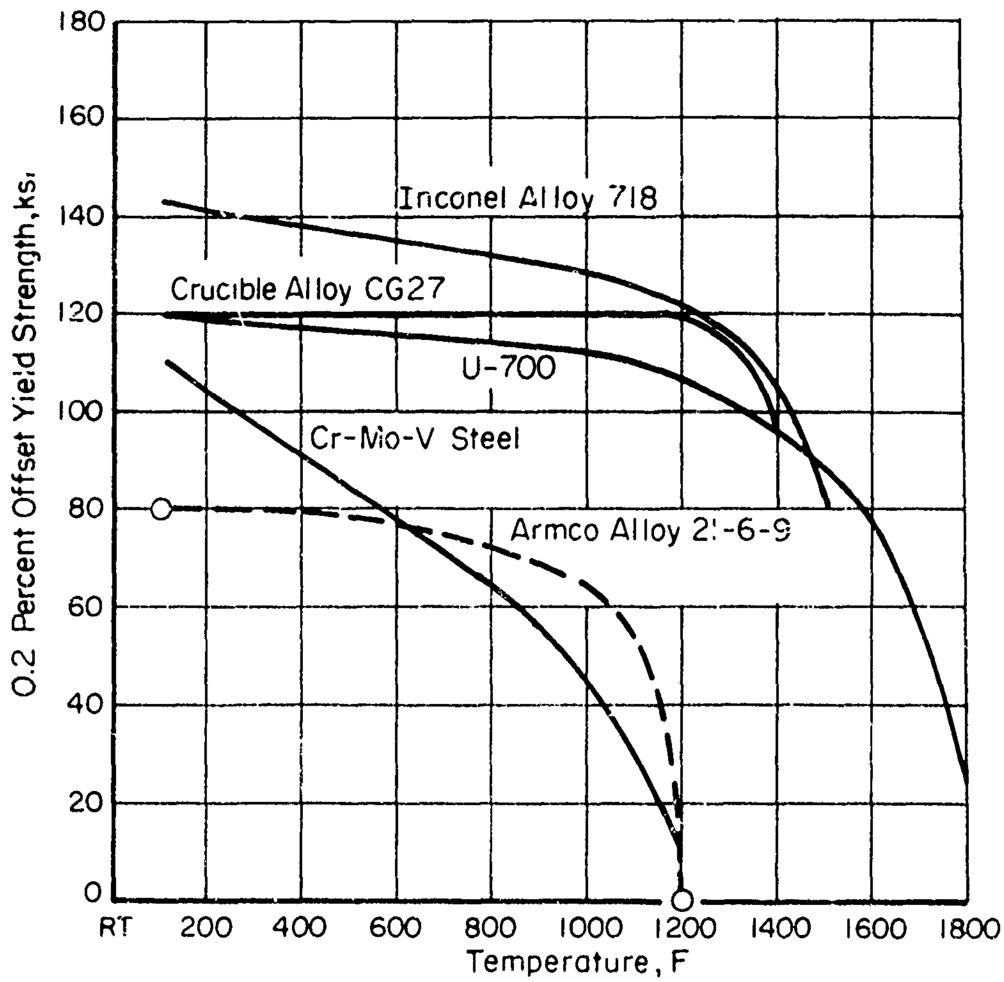


FIGURE 1 Interior Configuration, 7.62mm Gun Barrel



Note: Data for Armco Alloy 21-6-9 for room temperature and 1200 F only, curve is estimated.

FIGURE 2 High-Temperature Yield Strengths of Selected Gun Barrel Materials Compared to Cr-Mo-V Steel

The five companies listed below were consulted to learn more about the experience they have had in the swaging of gun barrels:

- Cincinnati Milling Machine Company
- Champion Tool and Die Company
- Fellows Gear Shaper Company
- Atrax Division of Wallace-Murray Corporation
- Fenn Manufacturing Company

Champion Tool and Die Company, and Fellows Gear Shaper Company have had a great deal of experience in the production of gun barrels by swaging. Fellows uses a Multiflow machine, which they designed and manufacture. Champion uses an Intraform machine, which was designed and is manufactured by the Cincinnati Milling Machine Company.

The Atrax Division is a supplier of high-quality tungsten carbide rifling mandrels used in the swaging of gun barrels. Furthermore, they are the only known company, according to Champion and Fellows, that has the capability to machine the required precise rifling grooves in the carbide mandrels.

Fenn Manufacturing Company is a manufacturer of two- and four-die rotary swagers. They have not done any gun barrel swaging, but have had some experience with swaging of tubes with various internal configurations.

From the discussions with the appropriate personnel at the aforementioned companies, the conclusions were that (1) a two-die swager will not yield the required accuracy for cold swaging gun barrels, (2) a four-die swager with a very large capacity is required for gun barrel swaging, (3) full-length rifling mandrels cannot be used in the swaging of gun barrels because they will shear during the elongation of the workpiece, (4) short tungsten carbide mandrels must be used to swage the ID contour of gun barrels, and (5) neither the Cincinnati Intraform nor the Fellows Multiflow machine is capable of hot swaging.

EXPERIMENTAL WORK

Materials

The certified chemical compositions of the alloys selected for this investigation are given in Table I. The alloys were procured in the form of annealed, centerless ground rods. All materials except Crucible CG-27 were received in the condition ordered, which is given in Table II. After the Gun barrel blanks of CG-27 had been prepared, hardness measurements indicated that the alloy was supplied in the aged condition rather than in the solution-annealed condition. Therefore, the gun barrel blanks of CG-27 were annealed since this alloy would be expected to exhibit better cold-forming behavior in the annealed condition. The heat treatment of the CG-27 blanks is discussed later.

With the exception of Inconel 718, the rods of each alloy were 1.600 inches in diameter. Inconel 718 was ordered and received as 1.500-inch-diameter rods because this size was available from stock. In addition, 1.015-inch-diameter Inconel 718 rod was purchased for use in the preliminary cold swaging trials discussed in the following section.

Preliminary Cold-Swaging Trials

The Columbus Laboratories of Battelle has a 2-die rotary swager, made by Fenn Manufacturing Company, which was designed to handle rods up to a diameter of 3/4 inch. However, the Laboratories were informed by Fenn that the swager might well be capable of reducing the nominal 1.5 inch OD X 0.330-inch ID tubes required for the gun barrel blanks.

To determine the capabilities of the swager, a 1.015-inch-diameter round bar of Inconel 718 in the solution annealed condition (1950°F - 1 hour - air cooled) was cold swaged to approximately 20 per cent reduction in area in one pass. The rod was held manually. During the swaging operation, the swager nearly stalled. In addition, the Inconel 718 rod became slightly bent because of manual swaging.

On the basis of the results of the preliminary cold swaging trials, conclusions were that (1) the Fenn swager does not have enough capacity to form gun barrels from 1.5-inch-diameter tubes and (2) an elaborate special fixture would be required to hold the workpiece during the swaging operation to maintain straightness.

TABLE I CERTIFIED CHEMICAL COMPOSITION OF ALLOYS

Alloy	Chemical Composition, percent											
	Fe	Cr	Ni	Co	Mo	Cb	Ti	Al	Mn	C	Si	B
Inconel Alloy 718	19.14	17.70	52.99	0.21	3.04	5.40(a)	0.99	0.47	0.08	0.051	0.18	0.025
Armco Alloy 21-6-9	Balance	20.04	6.67	-	-	-	-	-	8.73	0.007	0.19	-
Udimet Alloy U 700	00.25	15.0	Balance	18.7	4.80	-	3.46	4.30	0.10(b)	0.07	0.10(b)	0.030
Crucible Alloy CG-27	Balance	12.74	37.46	-	5.68	0.91	2.55	1.61	-	0.07	-	0.009

(a) Cb + Ta

(b) Maximum

TABLE II SPECIFIED HEAT TREATMENT OF ALLOYS FOR COLD-SWAGING TRIALS

Alloy	Specified Heat Treatment
Inconel Alloy 718	1950 F - 1 hour - air cool
Armco Alloy 21-69	1950 to 2050 F - 1 hour - rapid air cool
Udimet Alloy U 700	1925 F - 1 hour - air cool
Crucible Alloy CG-27	1875 to 1900 F - 1 hour - oil quench

Preparation of Gun Barrel Blanks

The rods of each alloy were cut and faced-off to a length of 20 inches. Then the rods were gun drilled and machined by Howard Dearborn, Inc., Berea, Ohio, into blanks designed as shown in Figure 3 to yield full-length gun barrels. The final OD of the Inconel 718 was slightly under 1.500 inches, since the starting diameter was only 1.500 inches. The major function of the machining operation was to obtain concentricity of the outer diameter (OD) and the inner diameter (ID) which is very critical in swaging gun barrel blanks.

Heat Treatment of Crucible Alloy CG-27 Blanks

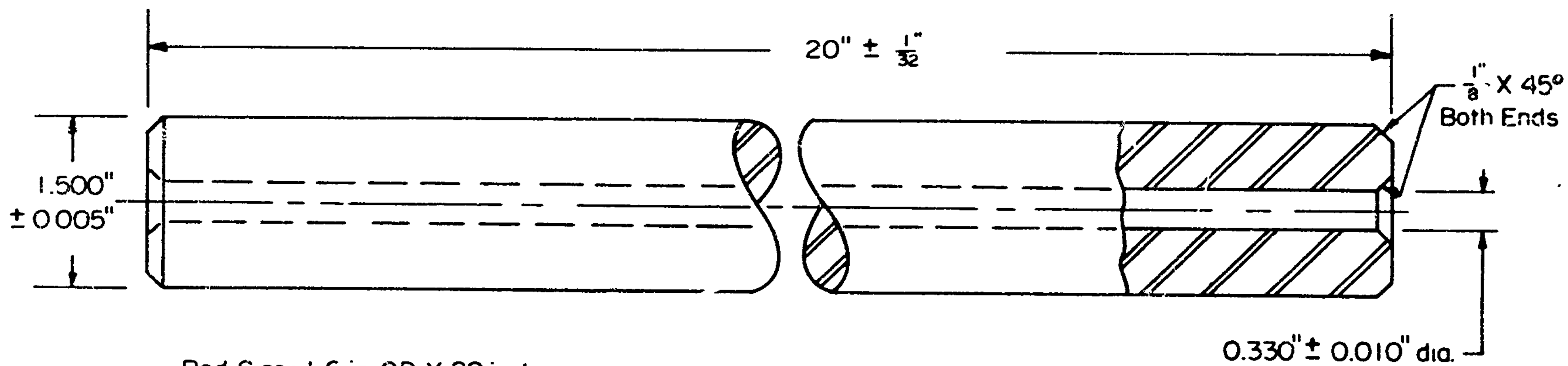
As mentioned previously, heat treatment of the Crucible CG-27 gun barrel blanks was necessary since this material was not supplied in the solution-annealed condition.

Prior to heat treating all CG-27 blanks, a brief study was made to determine the effect of the heat-treating time and cooling method on the hardness and straightness of the alloy. Blank 41, a 3-3/4-inch-long piece of Blank 46, and 1-inch-long pieces of the undrilled 1.600-inch-diameter rod were annealed at 1900°F for 1 to 4 hours and air cooled or oil quenched.

The hardness data given in Table III indicated that, with air cooling, the optimum annealing time was between 2 and 3 hours. With oil quenching, the hardness dropped to a much lower hardness level.

In another experiment, a gun barrel blank, No. 41, was annealed in an argon atmosphere at 1900°F for 1 hour and air cooled. The straightness of this blank was off by a total indicator reading (T.I.R.) of only 0.002 inch.

Since the straightness of Blank 41 was very good, the remaining blanks of Crucible CG-27 were heat treated by use of air cooling rather than oil quenching, even though the terminal hardness was 15 Rockwell C points higher for air-cooled material. However, the higher hardness level was not expected to impair the swageability of the alloy, while the possibility of warpage occurring is reduced by air cooling rather than oil quenching.



Rod Size: 1.6 in. OD X 20 in. Long
OD-ID Concentric within 0.002 in. per in. as gun drilled
ID Surface Finish: 125 RMS max.
OD Surface Finish: 125 RMS max.

FIGURE 3 Gun Barrel Blank

TABLE III. HARDNESS OF SAMPLES OF CRUCIBLE ALLOY CG-27 HEAT TREATED AT 1900 F

Sample Number	Time at Temperature, hr	Cooling Method	Hardness, Rockwell C
461-462	1.0	Rapid air cool	34
4-1	2.0	Slow air cool	32
4-2	3.0	Slow air cool	33
4-3	4.0	Oil quench	17
461-462(a)	1.0	Slow air cool	33

(a) This sample was given an additional 1 hour heat treatment and slow air cooled to determine the effect of cooling rate.

Thus, full-size Blanks 41, 42, 43, 44, and 45, and 2-1/2- and 9-inch lengths of Blank 46 were annealed in an argon atmosphere at 1900°F for 2-1/2 hours (Blank 41 had a total of 3-1/2 hours at 1900°F) and air cooled. The straightness of the full-length blanks varied from 0.003 to 0.007 inch T.I.R. The measurements for each blank were as follows:

Blank	Straightness (In.) - T.I.R.
41	0.007
42	0.004
43	0.006
44	0.003
45	0.0034

After the heat treatment, the Crucible CG-27 blanks were vapor blasted on the ID and OD to remove a slight oxide film and then cleaned thoroughly with water and acetone.

Evaluation of Gun Barrel Blanks

Machinability

The machinability rating of the alloys, based on facing off the ends, machining the OD, and gun drilling are as follows:

Rating	Alloy
1	Armco 21-6-9 (easiest to machine)
2	Udimet 700
3	Crucible CG-27
4	Inconel 718 (most difficult to machine)

Armco 21-6-9 was much easier to machine than any of the other alloys. On the other hand, a large difference did not occur in the machinability among Udimet 700, Crucible CG-27, and Inconel 718.

Surface Finish

Surface roughness measurements were made on the ID and OD of the gun barrel blanks of each alloy. A blank was sectioned for longitudinal measurement of the roughness along the surface of the ID and for metallographic studies. The surface finish was determined by centerline average (CLA) which has replaced the RMS method.

The following data show that a good surface was obtained on the ID by gun drilling The OD surface was also quite smooth

		Surface Finish, Microinch	
Alloy	Sample	ID	OD
Inconel 718	163B	52	70
Armco 21-6-9	263B	17	56
Udimet 700	363B	32	142
Crucible CG-27	463B	26	125

Metallographic Studies

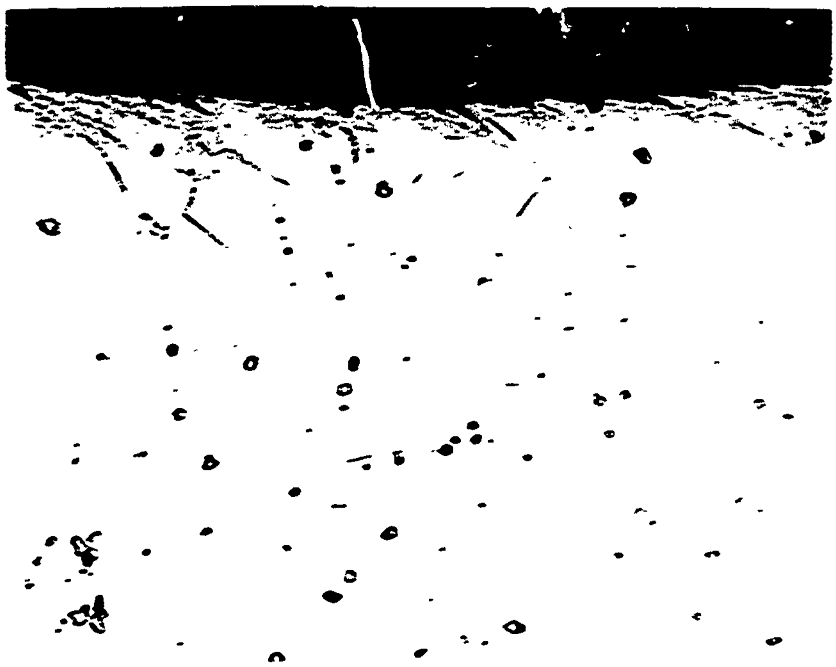
A gun barrel blank of each alloy was cut into transverse and longitudinal sections and prepared for metallographic examination. Photomicrographs of the transverse sections at the ID of the alloys are presented in Figure 4.

Metallographic examination of Inconel 718 revealed the typical microstructure for this alloy in the solution-annealed condition (1950 F - 1 hour - air cool). The alloy consists of a generally fine-grained austenitic matrix containing a moderate amount of intragranular precipitates, presumed to be complex carbides and carbonitrides In the longitudinal sample, the precipitates tended to be aligned in stringers running parallel to the long axis of the blank.

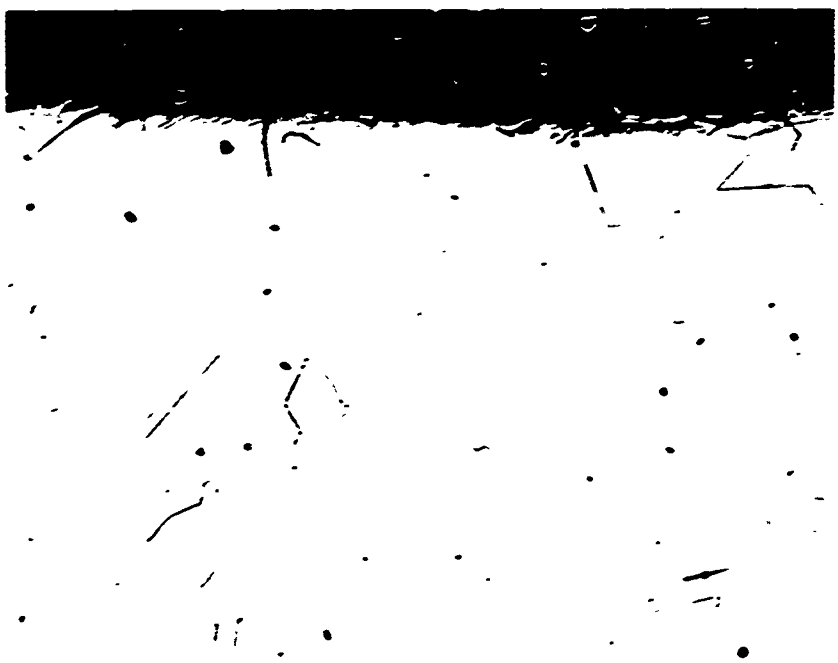
The microstructure of Armco 21-6-9 consists of a fine-grained austenitic matrix containing a small quantity of gray nonmetallic inclusions, presumed to be manganese sulfide These inclusions tended to be aligned with the long axis of the blank in the longitudinal sample.

The microstructure of Udimet 700 consists of a very fine-grained, mottled austenitic matrix with a large quantity of inter- and intragranular precipitates, presumed to be complex carbides and carbonitrides The precipitates are aligned in bands in the longitudinal direction The pronounced banding indicates a lack of homogeneity in the alloy

Examination of Crucible CG-27 revealed a very fine-grained, austenitic matrix containing generally small spherical inter- and intragranular precipitates, but with

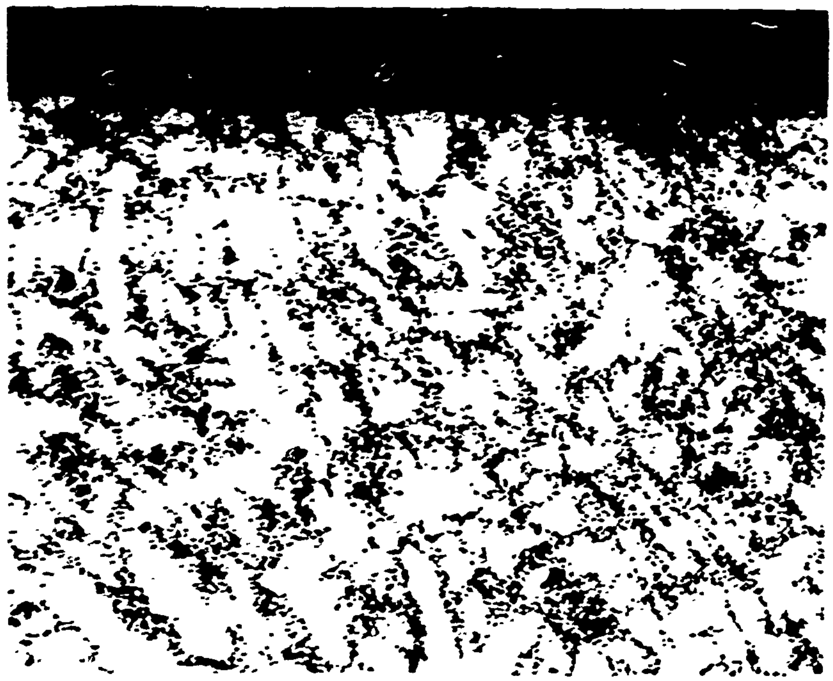


200X 20 Glycerine-20 HCl-10 HNO_3 8E273
Inconel 718: Sample No. 166
Heat Treatment: 1950 F - 1 hour - air cool



200X 20 Glycerine-20 HCl-10 HNO_3 8E274
Armco 21-6-9: Sample No. 266
Heat Treatment: 1950-2050 F - 1 hour - rapid air cool

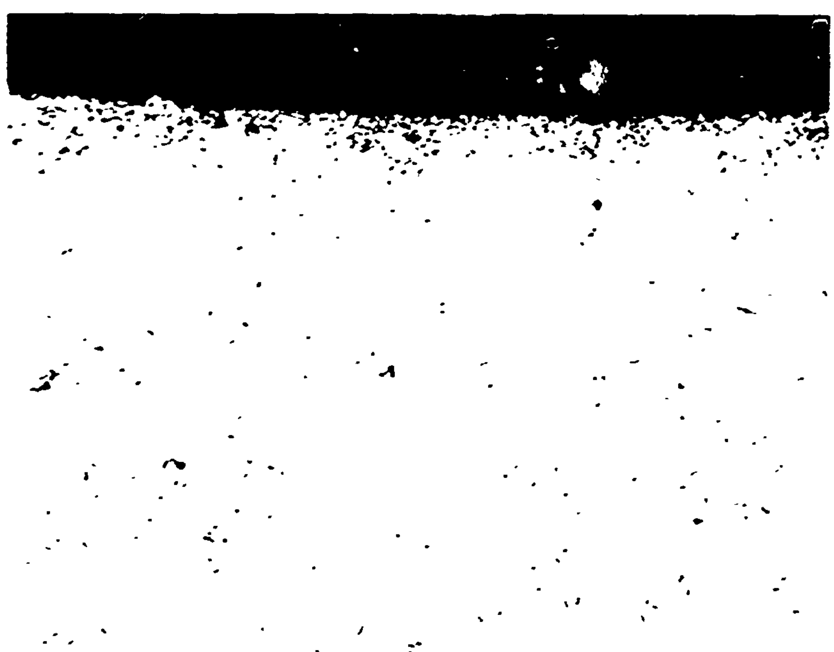
FIGURE 4 Transverse Sections of Gun Barrel Blanks



200X 95 HCl-2 HNO_3-1/2 g $CuCl_2$ 8E271

Udimet 700: Sample No. 366

Heat Treatment: 1925 F - 1 hour - air cool



200X 20 Glycerine-20 HCl-10 HNO_3 8E275

Crucible CG-27: Sample No. 468

Heat Treatment: 1900 F - 2-1/2 hours - rapid air cool

FIGURE 4 (Continued)

Transverse Sections of Gun Barrel Blanks a few large precipitates that appear to be titanium carbonitrides. A tendency exists for the small precipitates to be located intragranularly near the ID and OD, but intergranularly at the interior of the wall of the blank. The grain boundary precipitates are discontinuous. A slight longitudinal alignment of the precipitates occurs in the longitudinal sample.

Hardness Studies

Vickers hardness measurements were taken on the transverse metallographic samples of the gun barrel blanks of the alloys. Five hardness measurements were made along four radial traverses on each alloy. The radial traverses were approximately 45 degrees apart with impressions about 100 mils (0.1 inch) from each other.

The hardness data are presented in Table IV. These data indicate that the hardness of Inconel 718 is somewhat higher than expected, while the hardness of Armco 21-6-9 and Udimet 700 is just about the typical value for these alloys. The hardness of CG-27 is close to the anticipated value, based on the data obtained and presented in an earlier section of this report concerning the preparation of the gun barrel blanks. However, the hardness is about 19 Rockwell C points higher than that of material that is oil quenched rather than air cooled after solution annealing.

The data show that the hardnesses of Armco 21-6-9 and Udimet 700 are lowest near the ID and become increasingly higher toward the OD. On the other hand, Inconel 718 is hardest near the ID and becomes increasingly softer toward the OD. Crucible CG-27 shows a slight hardness trend similar to that of Inconel 718.

Based on the hardnesses of the alloys, Armco 21-6-9 and Inconel 718 were expected to exhibit the best formability during the swaging of the gun barrels. Crucible CG-27 was expected to exhibit slightly poorer forming behavior than Inconel 718, while the formability of Udimet 700 was expected to be less than that of Crucible CG-27.

Cold Swaging of Gun Barrels

Fellows Gear Shaper Company in Springfield, Vermont, was selected as the contractor for the swaging. Fellows was chosen because this company has (1) swaging machines

TABLE IV HARDNESS OF TRANSVERSE SECTIONS OF GUN BARREL BLANKS

Alloy[a]	Location[b] of Hardness Impressions	Hardness, VHN (10-kg Load): Distance From ID, mils: 85	185	285	385	485	Average[c]	Overall: Range	Overall: Average[c]
Inconel Alloy 718 (166)	1	314	294	266	249	247	274 (27)	243-327	282 (28)
	2	294	281	274	272	243	272 (26.5)		
	3	304	309	283	289	283	292 (29.5)		
	4	327	285	285	283	276	290 (29)		
Armco Alloy 21-6-9 (266)	1	196	191	207	213	230	207 (14)	191-242	209 (14.5)
	2	193	205	209	212	240	211 (15)		
	3	198	201	205	209	225	207 (14)		
	4	197	193	209	215	242	211 (15)		
Udimet 700 (366)	1	397	397	413	401	413	404 (42)	394-437	405 (42)
	2	397	405	413	415	437	413 (43)		
	3	397	394	401	409	417	402 (42)		
	4	394	394	401	401	413	400 (41.5)		
Crucible Alloy CG-27 (468)	1	342	339	339	336	339	339 (35.5)	336-363	342 (36)
	2	342	342	348	348	336	343 (36)		
	3	339	339	342	351	342	342 (36)		
	4	336	342	342	351	363	347 (36.5)		

(a) Heat treatment of each alloy is given in Table II. Numbers in parentheses are sample numbers.

(b) The hardness impressions were taken along four radial traverses which were about 45 degrees apart.

(c) Numbers in parentheses are Rockwell C hardness numbers converted from the Vickers hardness number. The converted Rockwell C hardness numbers are for reference only, since the accuracy of the conversion is not known.

capable of producing gun barrels with rifling grooves, (2) a great deal of experience with internal swaging of contours including the rifling in gun barrels, (3) offered to furnish the required tooling including swaging dies and mandrels, and (4) offered to conduct the swaging trials at a reasonable cost.

Equipment and Tooling

A photograph of the Fellows Multiflow machine used for the experimental cold swaging of the 7.62mm rifled gun barrels is shown in Figure 5. The Multiflow machine was designed and built by Fellows. It is a stationary 4-die machine with a 500-ton load capacity. The machine has automatic feeding and positioning mechanisms which position the mandrel in the dies, rotate the blank counterclockwise and feed the blank over the mandrel and through the swaging dies. The mandrel is held in a predetermined axial position in the dies, but is free to rotate. During the swaging operation, the dies and blank are flooded with a coolant called Mentor 28.* The dies contact the blank at the rate of 1500 times per minute. A work receiver located on the exit side of the die exerts back pressure on the gun barrel blank, as it leaves the die, which helps maintain the straightness of the blank during swaging. The work receiver is hollow so that the coolant, Mentor 28, can be forced into the bore of the gun barrel blank during swaging to cool the mandrel and the blank. After the blank is formed, the dies automatically open, the receiver pushes the blank back to its original starting point, and the finished blank is lifted from the machine cradle.

A drawing (Fellows Drawing D-4324-FA) of the dies designed by Fellows Co. and used in the swaging of gun barrel blanks is included as Figure 6. The dies were made from SAE M2 nonresulphurized steel hardened to 59 to 61 Rockwell C and bright stress-relieved after the profile section of the dies was finished.

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*A product of Esso International, Inc., New York, New York 10019

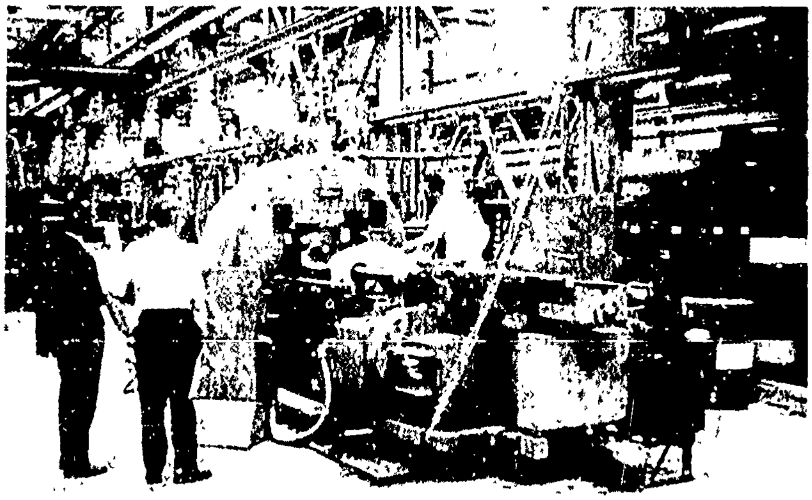


FIGURE 5 Multiflow Machine During Cold Swaging of Gun Barrel Blanks

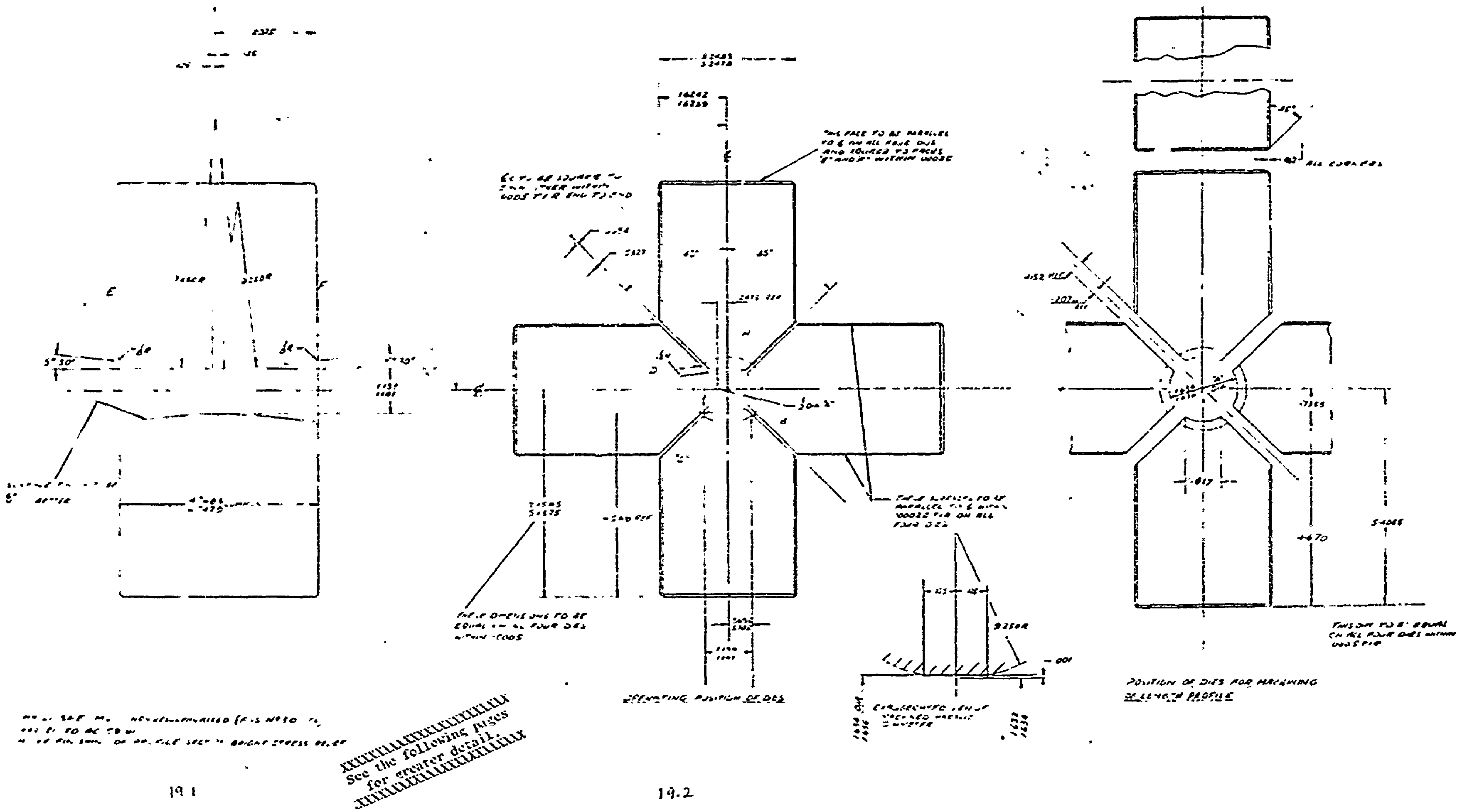
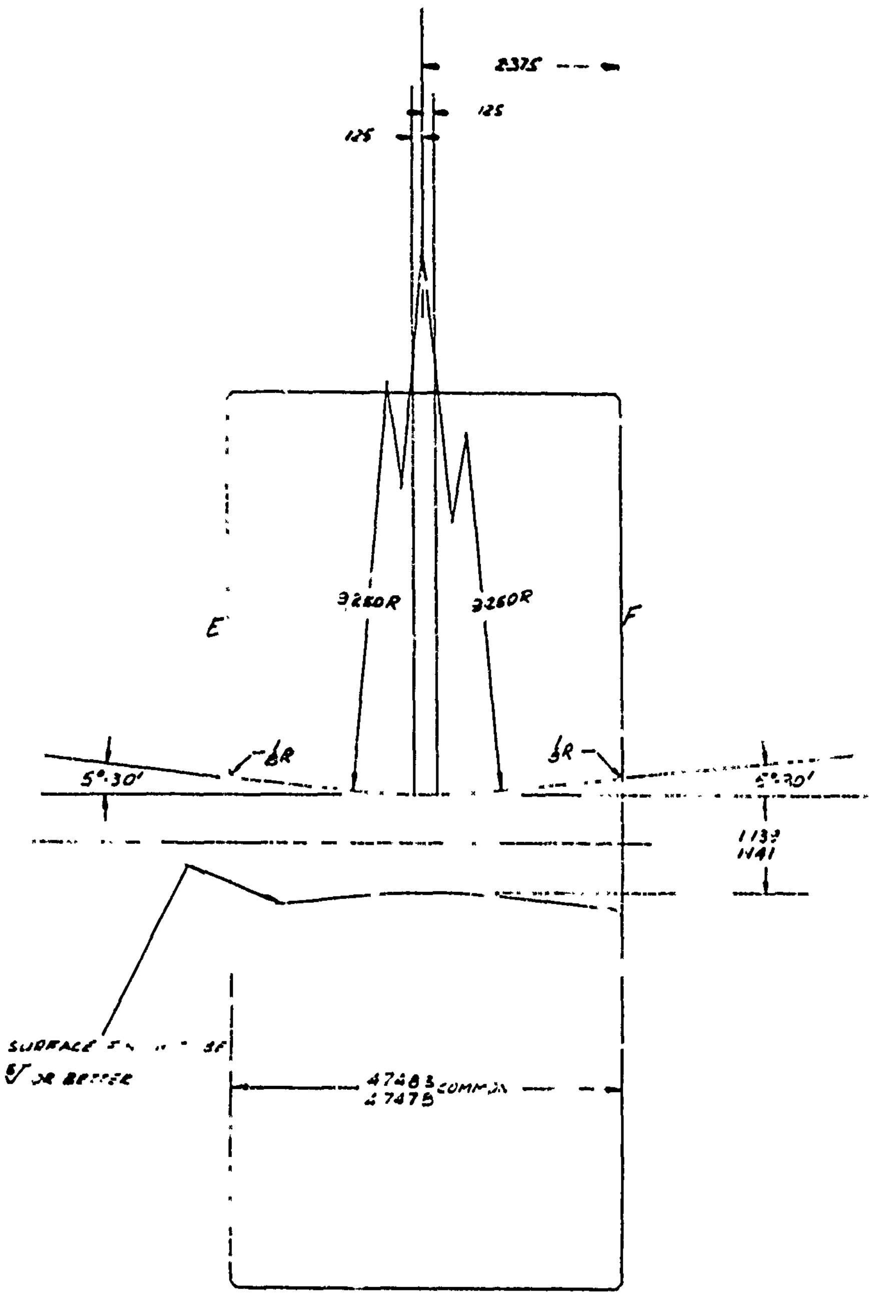


FIGURE 6. DRAWING OF DIES USED TO COLD SWAGE GUN BARRELS IN MULTIFLOW MACHINE



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AFTER FINISHING OF PROFILE SECTION BRIGHT STRESS RELIEF

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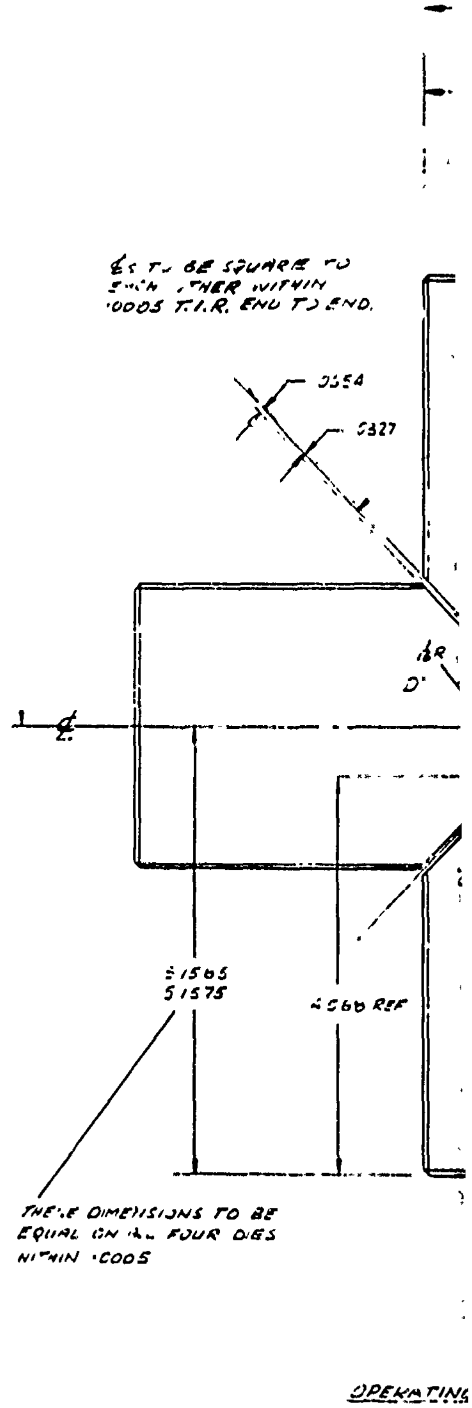
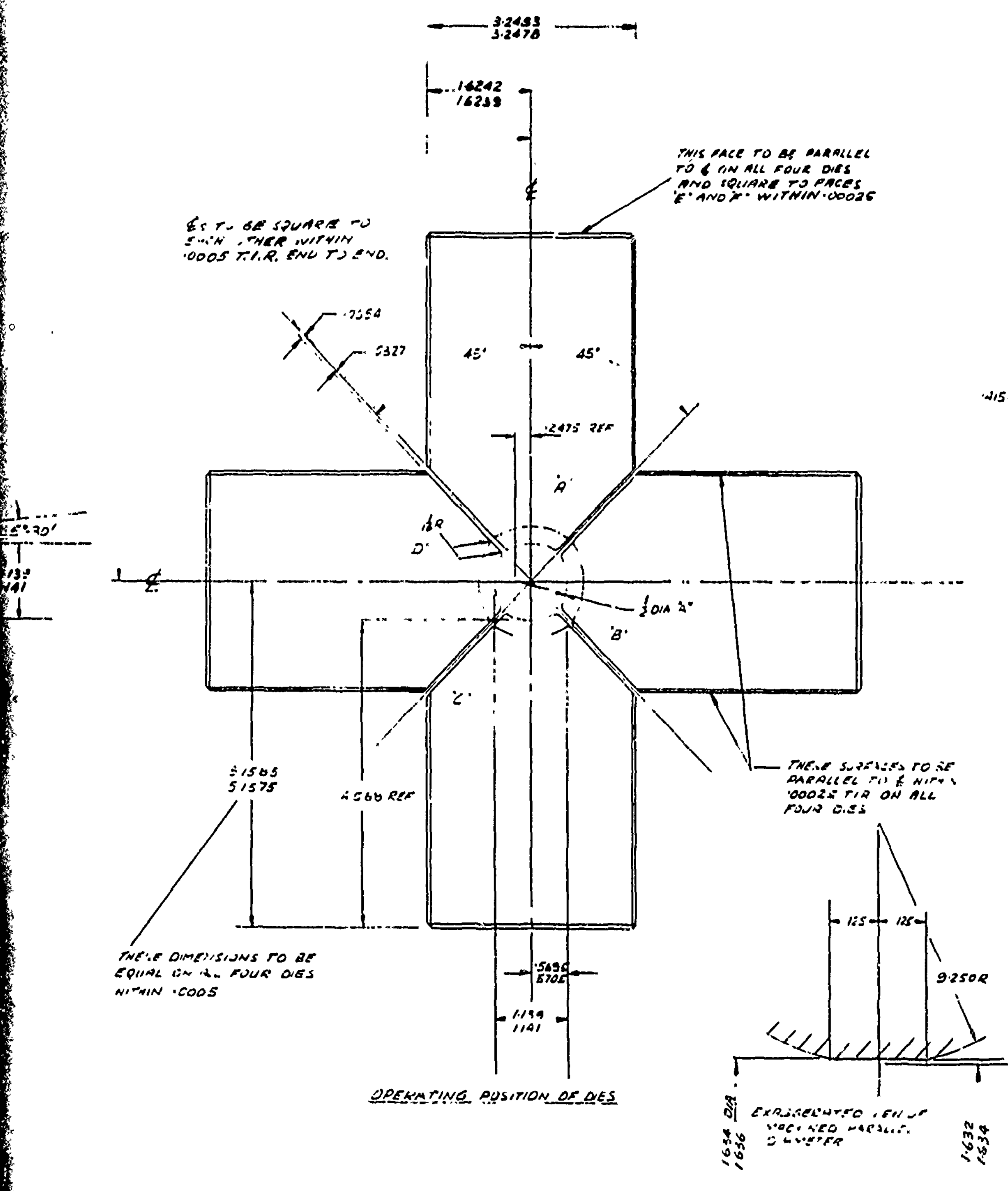


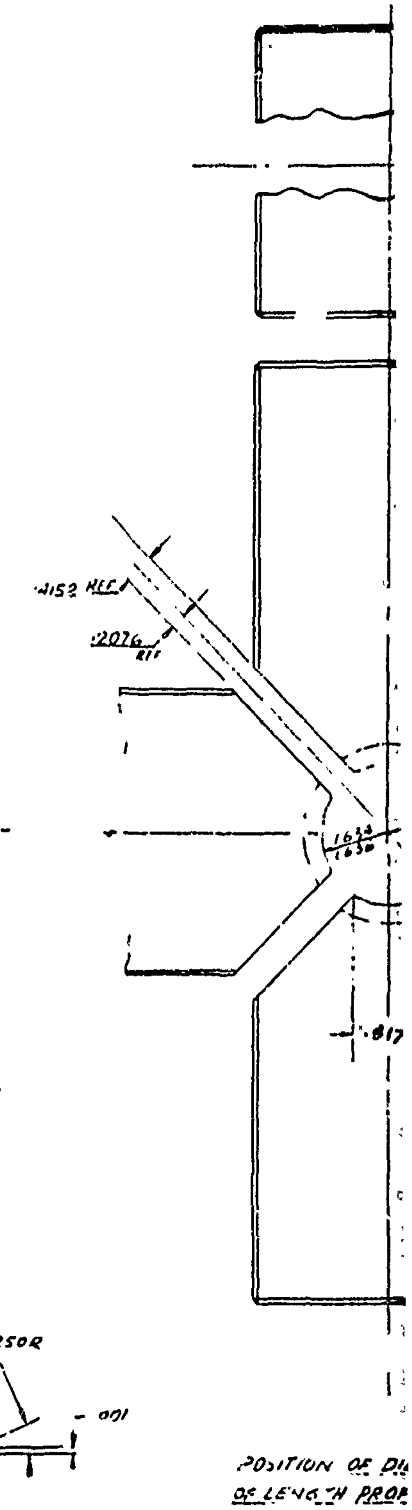
19.

FIGURE 6. DRAWING OF D
IN MULTIFLOW

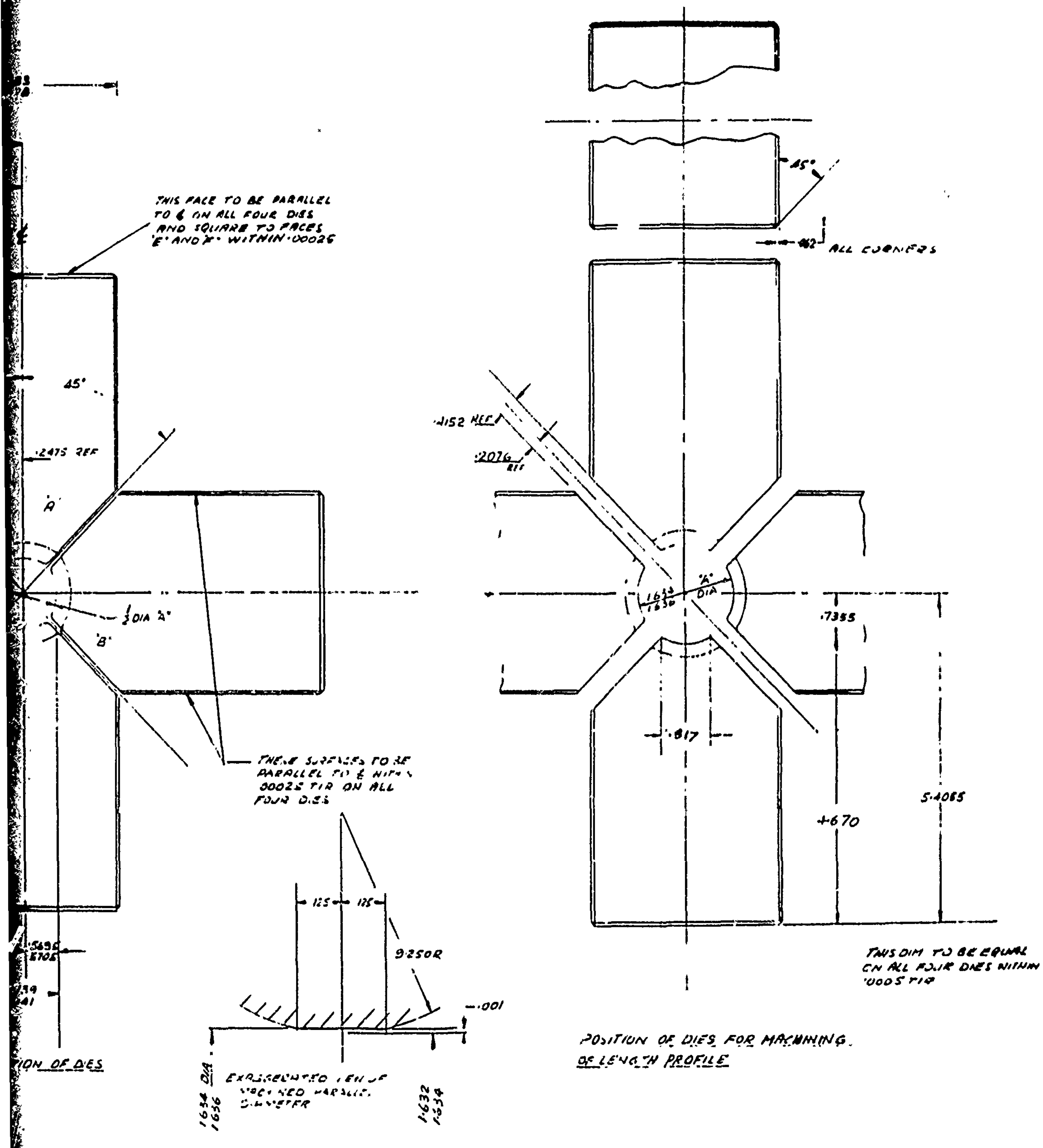


19.2

FIGURE 6. DRAWING OF DIES USED TO COLD SWAGE GUN BARRELS IN MULTIFLOW MACHINE



19.3



SED TO COLD SWAGE GUN BARRELS
CHINE

A drawing (Fellows Drawing 65-05-1047-2) of the rifling mandrel is shown in Figure 7. The mandrel was designed by Fellows Co. to produce the specified bore for the 7.62mm gun barrels. Three mandrels were made for Fellows by Atrax Division of Wallace-Murray Corporation who, according to several sources including Fellows, is the only company that has the capability of machining the rifling in the mandrels. One mandrel was machined from General Electric Carboloy, Grade 248, while the other two were machined from General Electric Carboloy, Grade 55B. Both grades performed well.

The rifling mandrel was silver soldered to the mandrel holder, which was described earlier.

Procedure

The following procedure was followed in swaging the gun barrel blanks:

(1) The ID and OD of each gun barrel blank was cleaned thoroughly with acetone and then swabbed with a gun cleaning rod and dry cloth swabs.

(2) The ID of each blank was coated thoroughly by swabbing and then pouring Houghton Cindol 624* lubricant through the blank.

(3) The blank was placed on the cradle of the Multiflow machine.

(4) The automatic sequencing was started in which the blank was positioned, the mandrel was inserted through the blank and positioned in the die, the driver and the receiver engaged the blank, and the blank was rotated and fed into the pulsating swaging dies.

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*A product of E. F. Houghton Company, Philadelphia, Pa. 19133

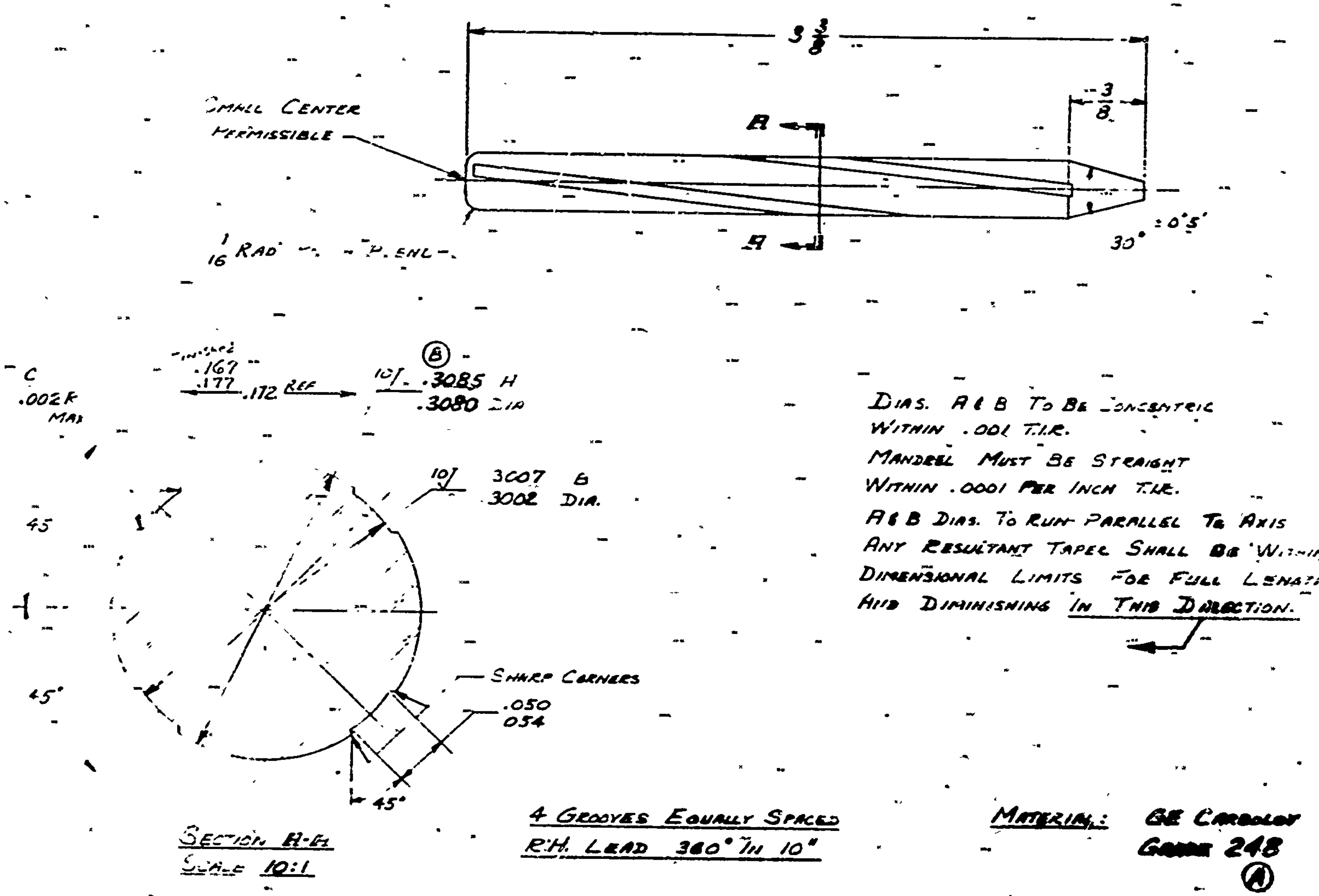


FIGURE 7. Carbide Rifling Mandrel used to form Bore Contour of Gun Barrels During Cold Swaging

(5) After the gun barrel blank was formed, the dies automatically opened, the receiver blank pushed the blank back to its original position, the mandrel was extracted and the blank returned to the cradle of the machine.

(6) The gun barrel blank was removed from the machine and the trailing end (about 10 inches) of the blank was immersed in a bucket of water. The water served to cool the blank and to clean out the lubricant.

(7) The ID of the barrel blank was cleaned with water-soaked swabs on a gun cleaning rod.

(8) The ID of the barrel blank was dried with swabs on gun-cleaning rods.

(9) The ID of the barrel blank was inspected by a borescope.

Results and Discussion

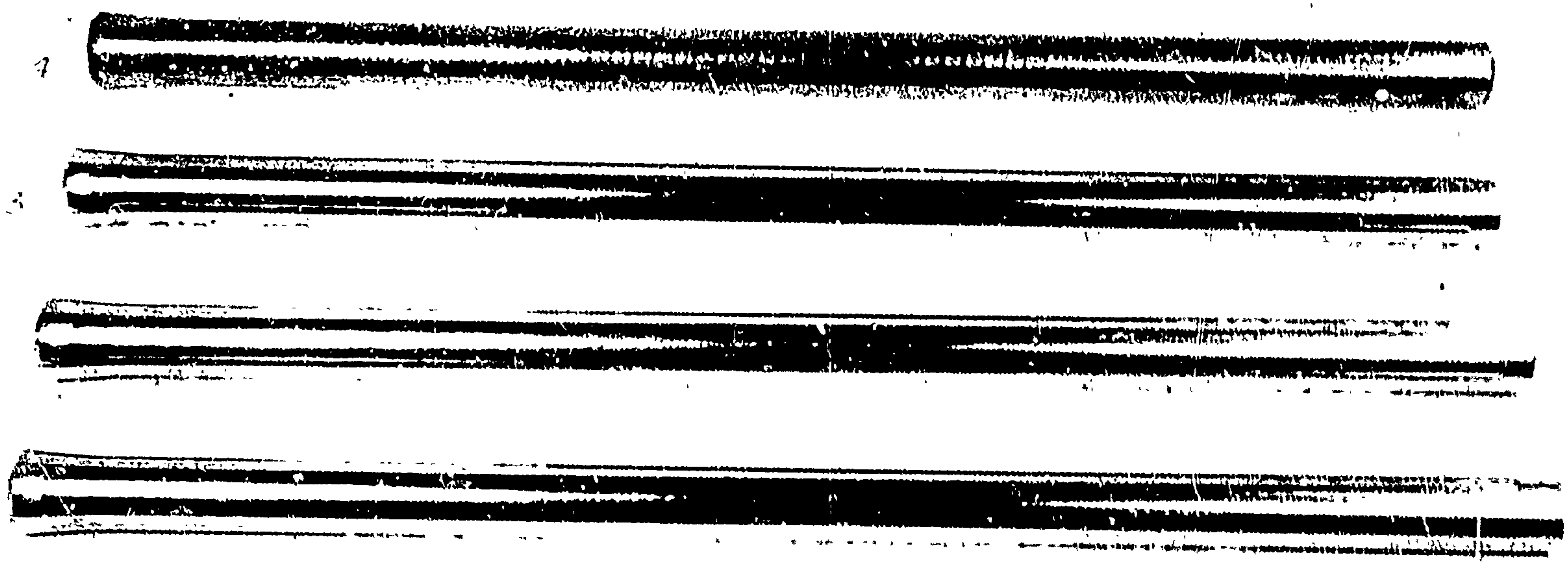
Five gun barrel blanks each of Inconel 718, Armco 21-6-9, and Crucible CG-27 and seven gun barrels of Udimet 700 were formed by cold swaging blanks of each alloy. Data taken during the cold swaging trials are given in Appendix A. A typical gun barrel blank of each alloy is shown in Figure 8. The length of the swaged blanks ranged from about 25-1/8 to 27-9/16 inches; the OD ranged from 1.260 to 1.330 inches, dependent upon the die closing setting (wedge position dial numbers in Table A-1).

No severe problems were encountered during the swaging of the blanks except with Crucible CG-27. Pickup of material on the mandrel occurred during the first three swaging trials with this alloy. Changing the following variables of the swaging process eliminated pickup on the mandrel:

(1) Feeding rate of the blank was decreased from 20 to 12 inches per minute.

(2) Rotational speed of the blank was decreased from 130 to 105 rpm.

(3) Thickness of the shims behind each of one pair of dies was increased from 0.004 to 0.008 inch.



No. 1: Barrel No. 15 - Inconel Alloy 718
No. 2: Barrel No. 25 - Armco Alloy 21-6-9
No. 3: Barrel No. 35 - Udimet 700
No. 4: Barrel No. 45 - Crucible Alloy CG-27

FIGURE 8 Gun Barrel Blanks Formed by Cold Swaging

Evaluation of Swaged Blanks

Nondestructive Testing

The bore of each gun barrel blank was examined twice with a borescope A cursory borescopic examination was made at Fellows Co immediately after each gun barrel blank was formed A detailed examination of the bore of each blank was made later. With the exception of the first three swaged gun barrel blanks (Nos. 41, 42, and 43) of Crucible CG-27, the examinations indicated that the rifling detail was good and the surface was smooth and free of cracks However, several of the blanks (Nos. 11, 14, 21, and 33) contained small defects that appeared to be an inherent defect in the material, rather than one caused by swaging. Pickup of material on the mandrel caused longitudinal scuffing along the lands of the Crucible CG-27 blanks (Nos 41, 42, and 43) Thus, these three CG-27 blanks (Nos 44 and 45) have good bore surfaces

Surface roughness measurements were taken on the ID of one as-swaged gun barrel blank of each alloy. A longitudinal section of the blank was used, and the finish along a longitudinal traverse was determined by the CLA method used earlier to determine the finish of the gun barrel blanks

The surface finish data for the ID of the cold-swaged gun barrel blanks, and for the ID of the gun drilled blanks, are presented in Table V. These data show that the surface finish of the ID of the swaged blanks is much better than that of the gun drilled blanks. Furthermore, the surface finish of the ID is better than that (25 microinches) specified for 7 62mm gun barrels in Rock Island Arsenal Drawing 11701204,dated April 14, 1965.

Inspection of the OD of the swaged blanks by use of dye penetrant indicated that all were free of cracks. Diameter measurements showed that maximum out-of-roundness was 0.001 inch.

Straightness measurements revealed that, in general, the straightness of the blanks was off from 0.003 to 0.009 inch T I R However, two Inconel 718 blanks had 0.013 inch T.I R , while another Inconel 718 blank had 0.026 inch T I R Generally, the barrel blank with the largest deviation was sectioned for metallographic examination and hardness determination, although the quality of the bore was also a determining factor.

TABLE V SURFACE FINISH OF BORE OF GUN DRILLED BLANKS AND SWAGED BLANKS

Alloy	Blank Sample Number		Surface Finish, CLA, Microinch	
	Swaged	Gun Drilled	Swaged	Gun Drilled
Inconel 718	125A	163B	10	52
Armco 21-6-9	225B	263B	12	17
Udimet 700	375A	363B	7	32
Crucible CG-27	451	463B	12	26

A tabulation of the diameter and straightness measurements is presented in Appendix B.

On the basis of the borescopic examination of the bore and the straightness measurements, a quality rating was assigned to each barrel blank. The ratings, given in Table VI, were made by a comparison of the blanks of the same alloy, rather than by a comparison of all blanks with each other.

Metallographic Examination of As-Swaged Samples of Gun Barrel Blanks

Longitudinal and transverse sections of one or more blanks of each alloy were removed and prepared for metallographic examination and hardness determinations.

Photomicrographs of transverse and longitudinal sections of a gun barrel blank sample of each alloy at the bore surface are shown in Figures 9 through 12. These photomicrographs show that the surfaces of the as-swaged samples of each alloy are very smooth. Also, the sharp detail of the lands for each of the samples can be seen.

The gun barrel blank sample of Udimet 700 contained occasional microtears along the bore surface at areas where precipitates intersected the bore surface. These microtears run about 1-mil deep and can be seen in Figure 11.

The microstructures of the as-swaged samples of all four alloys were similar to those observed in the samples of the gun drilled blanks, although slight differences occurred that had been produced by cold swaging. For example, the Inconel 718 and the Udimet 700 samples tended to have a shallow (from 0.5 to 1.5 mils deep) cold-worked layer along the bore. The Inconel 718 sample (Figure 9) contained coring lines throughout the longitudinal section. These coring lines indicate the existence of slight inhomogeneity in the chemical composition of the alloy. Armco 21-6-9 (Figure 10) also contained the coring lines as well as pronounced mechanical twins within the grains.

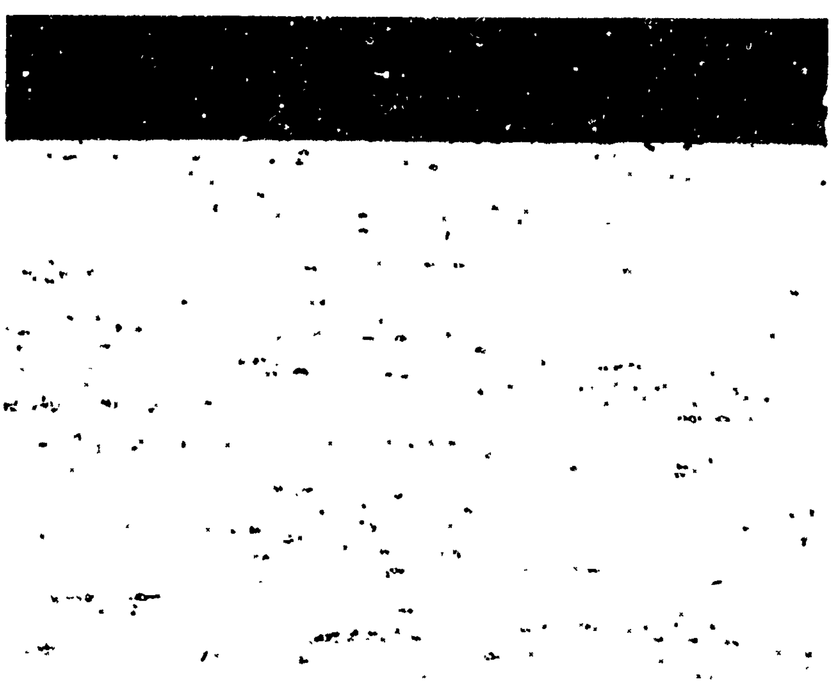
The grains in the transverse samples of each alloy are equiaxed and do not appear to be deformed. On the other hand, the grains in the longitudinal samples of Inconel 718, Armco 21-6-9, and Crucible CG-27 are elongated in a direction parallel to the axis of the blank. The longitudinal sample (Figure 11) of Udimet 700, however, does not show any appreciable evidence of cold work caused by swaging.

TABLE VI QUALITY RATING OF EXPERIMENTAL 7.62-mm GUN BARRELS

Gun Barrel Blank	Alloy	Quality Rating[a]
11	Inconel 718	4
12	Inconel 718	5
13	Inconel 718	2
14	Inconel 718	3
15	Inconel 718	1
21	Armco 21-6-9	1
22	Armco 21-6-9	5
23	Armco 21-6-9	3
24	Armco 21-6-9	4
25	Armco 21-6-9	2
31	Udimet 700	3
32	Udimet 700	5
33	Udimet 700	6
34	Udimet 700	2
35	Udimet 700	4
37	Udimet 700	7
38	Udimet 700	1
41	Crucible CG-27	5
42	Crucible CG-27	3
43	Crucible CG-27	4
44	Crucible CG-27	1
45	Crucible CG-27	2

(a) A rating of "1" indicates, for a particular alloy, the barrel with the highest quality.

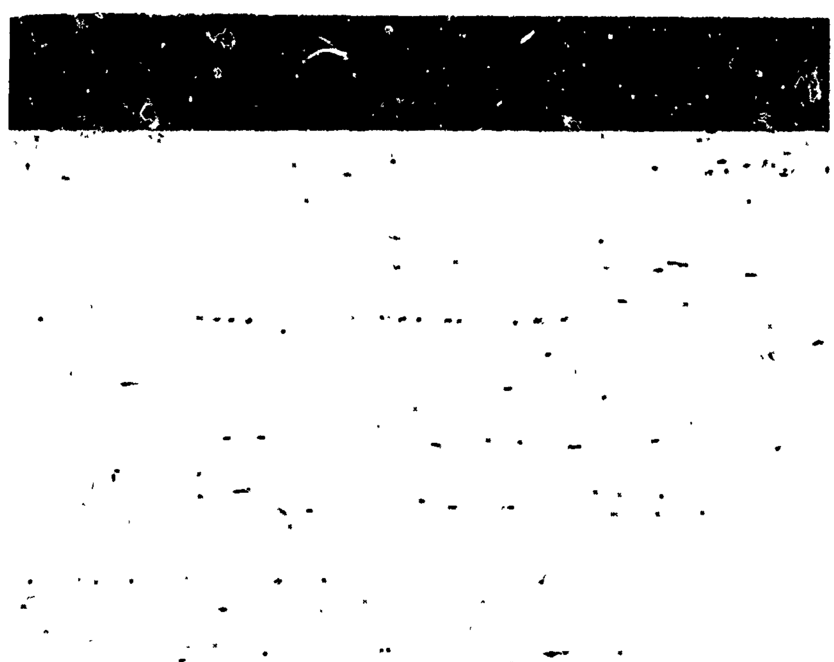
200X 20 Glycerine-20 HCl-10 HNO_3 8E269
Transverse Sample No. 126



55X 20 Glycerine-20 HCl-10 HNO_3 8E277
Longitudinal Sample 125BB

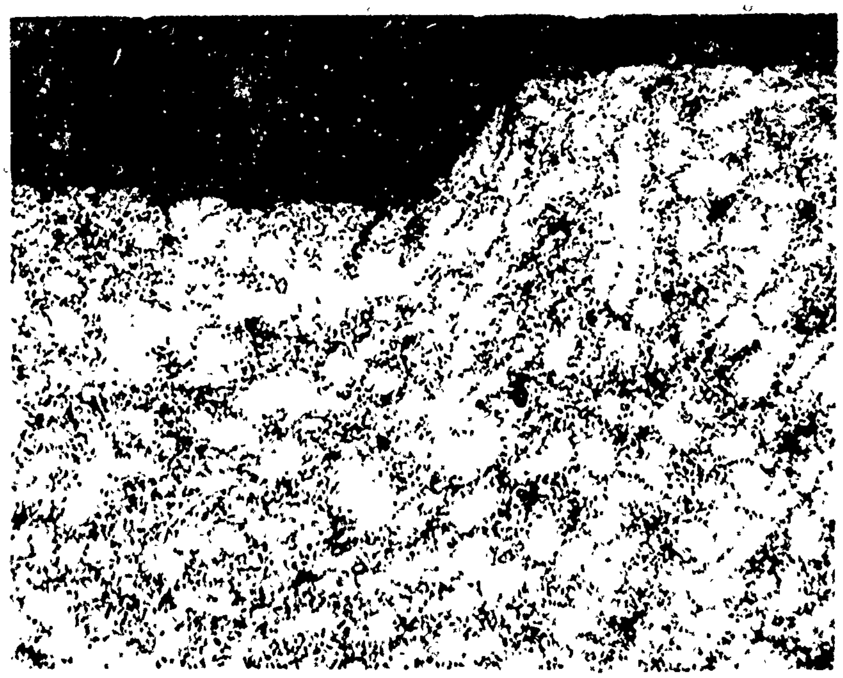
FIGURE 9 As-Swaged Inconel 718 Gun Barrel Samples

200X 40 HCl-10 HNO_3 8E268
Transverse Sample No. 226

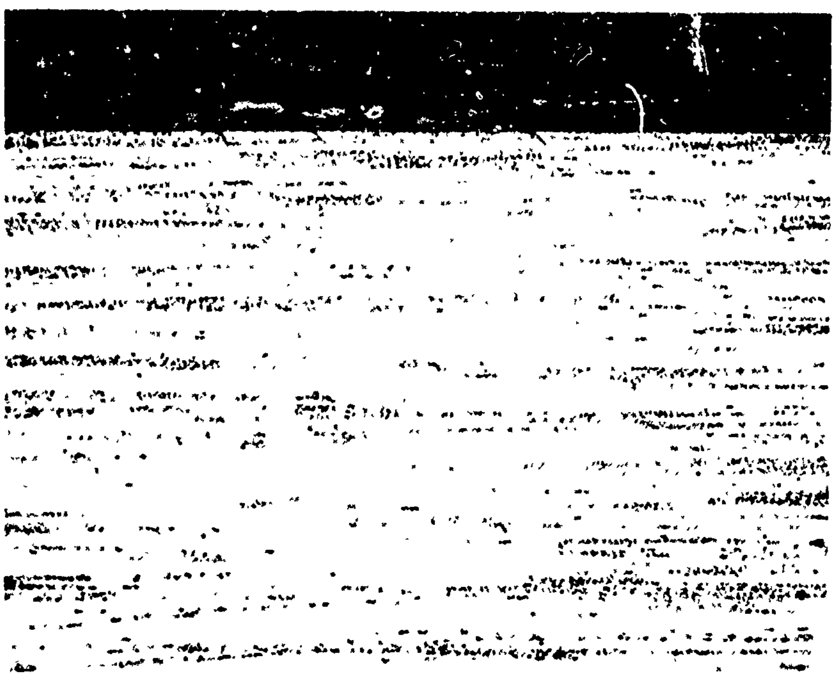


55X 20 Glycerine-20 HCl-10 HNO_3 8E280
Longitudinal Sample No. 225BB

FIGURE 10 As-Swaged Armco 21-6-9 Gun Barrel Samples

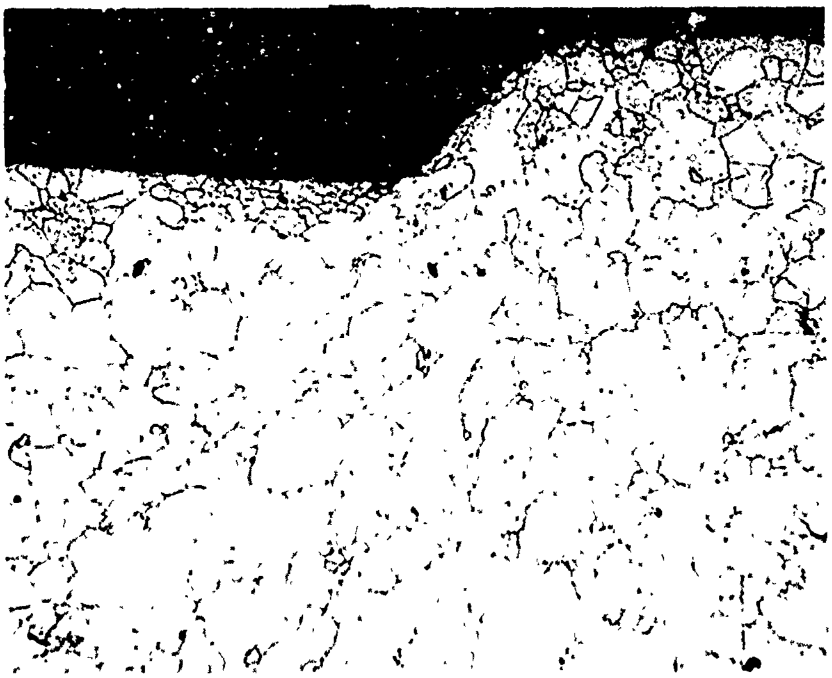


200X 95 HCl-2 HNO_3-1/2 g $CuCl_2$ 8E270
Transverse Sample No. 376

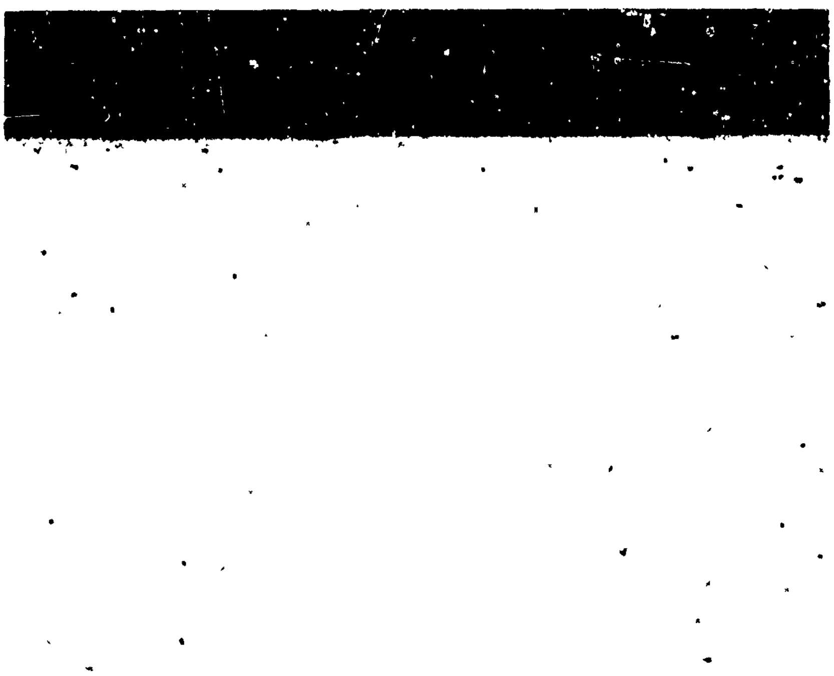


55X As Polished 8E278
Longitudinal Sample No. 375BB

FIGURE 11 As-Swaged Udimet 700 Gun Barrel Samples



200X 40 HCl-10 HNO_3 8E267
Transverse Sample No. 452



55X 20 Glycerine-20 HCl-10 HNO_3 8E276
Longitudinal Sample No. 451 B

FIGURE 12 As-Swaged Crucible Alloy CG-27 Gun Barrel Samples

Metallographic Examination of Heat-Treated Samples of Gun Barrel Blanks

Three of the four selected gun barrel materials, Inconel 718, Udimet 700, and Crucible CG-27, are age-hardenable. Thus, they are normally annealed and aged to develop maximum strength before being placed in service. The usual heat treatments for the three alloys are given in Table VII. Armco 21-6-9 is not hardenable by heat treatment; however, it is hardenable by working such as cold swaging.

TABLE VII HEAT TREATMENTS FOR AGE-HARDENABLE, SELECTED GUN BARREL MATERIALS

Udimet 700

Solution annealing:	2150°F/4 hr/AC
High-temperature aging:	1975°F/4 hr/AC
Intermediate aging:	1550°F/25 hr/AC
Final aging:	1440°F/16 hr/AC

Inconel 718

Anneal:	1800°F/1 hr/AC
Age:	Hold 8 hr at 1325°F, furnace cool to 1150°F at the rate of 100°F/hr, hold at 1150°F for 8 hr and air cool.

Crucible CG-27

Solution annealing:	1875 to 1900°F for 1/2 hr/OQ
Intermediate aging:	1450°F/16 hr/AC
Final aging:	1200°F/16 hr/AC

Transverse samples of the gun barrel blanks in the as-swaged condition were heat treated according to the treatments given in Table VII. These samples were used for metallographic and hardness studies. The only deviation was that the annealing time used for Inconel 718 was 1-1/2 hours rather than 1 hour.

Because of the concern regarding the effect of high-temperature annealing on straightness and on bore dimensions of gun barrels, additional transverse samples of age-hardenable alloys were given the aging heat treatment without annealing.

For all heat treatments, the following procedure was used:

(1) Each sample was degreased thoroughly with C.P. acetone.

(2) Each sample was sealed in a clean vycor tube after evacuating to about 10^{-5} torr, flushing several times with high-purity argon and then backfilling to about 1/2 atmosphere with the argon.

(3) The sample was annealed and aged or aged only according to the schedule in Table VII, except as previously noted for the Inconel 718 specimen. In the solution annealing of Crucible CG-27, the vycor tube was broken intentionally during the oil quench. The aging treatment for this sample was conducted in air.

The heat treatments of the various gun barrel blank samples are given in Table VIII.

Microstructures of transverse sections of the heat-treated samples of the swaged blanks are illustrated in Figures 13 through 15. The metallic layer along the core surface is a plating of nickel which was used to prevent rounding of the edges of the samples during preparation for metallographic examination.

Heat treatment of Inconel 718 resulted in a slight coarsening of the grains and the formation of a discontinuous grain-boundary phase or phases (believed to be a carbide or carbides) along with some intragranular precipitation (compare Figures 9 and 13). Examination of the sample revealed no cracking.

Heat treatment of Udimet 700 produced considerably larger grains than were present in the as-swaged sample. The heat-treated sample contains much fewer intergranular and intragranular precipitates (presumably carbides) than did the as-swaged sample, as can be seen by comparison of Figures 11 and 14. Several microtears where precipitates intersected the surface were observed, as noted earlier for the as-swaged samples.

TABLE VIII HEAT TREATMENTS USED FOR TRANSVERSE SAMPLES OF GUN BARREL BLANKS

Sample	Alloy	Heat Treatment[a]
126	Inconel 718	Solution annealed and aged
126B[b]	Inconel 718	Aged
376	Udimet 700	Solution annealed and aged
376B[b]	Udimet 700	Aged
452	Crucible CG-27	Solution annealed and aged
422[b]	Crucible CG-27	Aged

(a) Refer to Table VII for details of the heat treatments, except that the Inconel 718 specimen was solution-annealed for 1-1/2 hours rather than 1 hour.

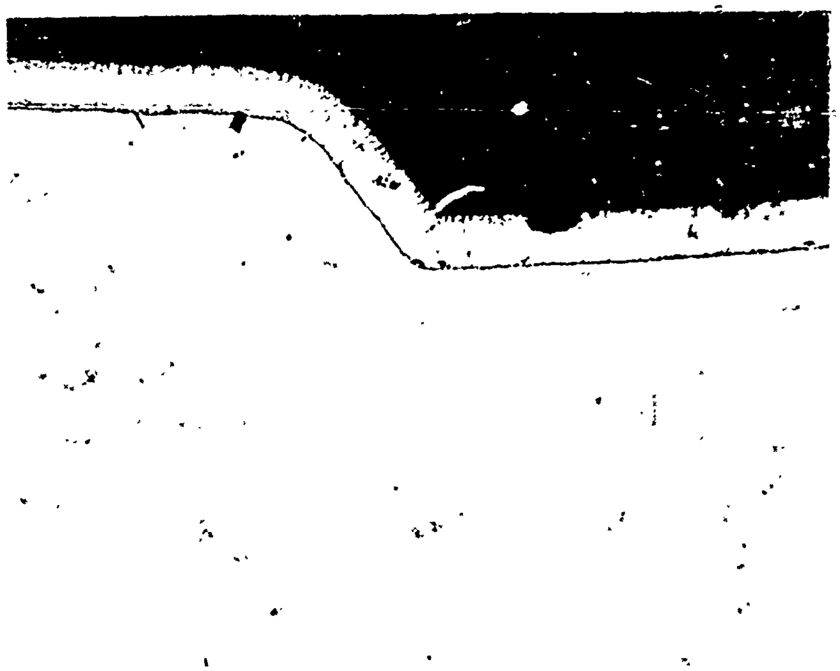
(b) These samples were sent to the U. S. Army Weapons Command at Rock Island for evaluation.

200X | 20 Glycerine-20 HCl-10 HNO_3 | 8E885

Transverse Sample No. 126

Heat Treatment: 1800 F-1-1/2 hour-air cool
1325 F- 8 hours-furnace cool to 1150 F
1150 F- 8 hours-air cool

FIGURE 13 Heat-Treated Inconel 718
Gun Barrel Sample



200X 20 Glycerine-20 HCl-10 HNO_3 8E886

Transverse Sample No. 376

Heat Treatment: 2150 F-4 hours-air cool
1975 F-4 hours-air cool
1550 F-25 hours-air cool
1440 F-16 hours-air cool

FIGURE 14 Heat-Treated Udimet 700
Gun Barrel Sample

200X 20 Glycerine-20 HCl-10 HNO_3 8E884
Transverse Sample No. 452

Heat Treatment: 1875 F-1-1/2 hours-oil quench
1450 F-16 hours-air cool
1200 F-16 hours-air cool

FIGURE 15 Heat-Treated Crucible CG-27
Gun Barrel Sample

Heat treatment of Crucible CG-27 caused a slight refinement of the grain structure. Most small intragranular precipitates present in the as-swaged sample (Figure 12) were apparently dissolved by the heat treatment (Figure 15). Heat treatment had no appreciable effect on grain-boundary precipitate which remained discontinuous. No evidence of cracking was observed in the heat-treated sample of Crucible CG-27.

Photomacrographs of the heat-treated samples of Inconel 718, Udimet 700, and Crucible CG-27 are shown in Figures 16, 17, and 18, respectively. A photomacrograph of the as-swaged sample of Armco 21-6-9 which was not heat treated is included as Figure 19. These photomacrographs show the contour of the bore discussed in the next section.

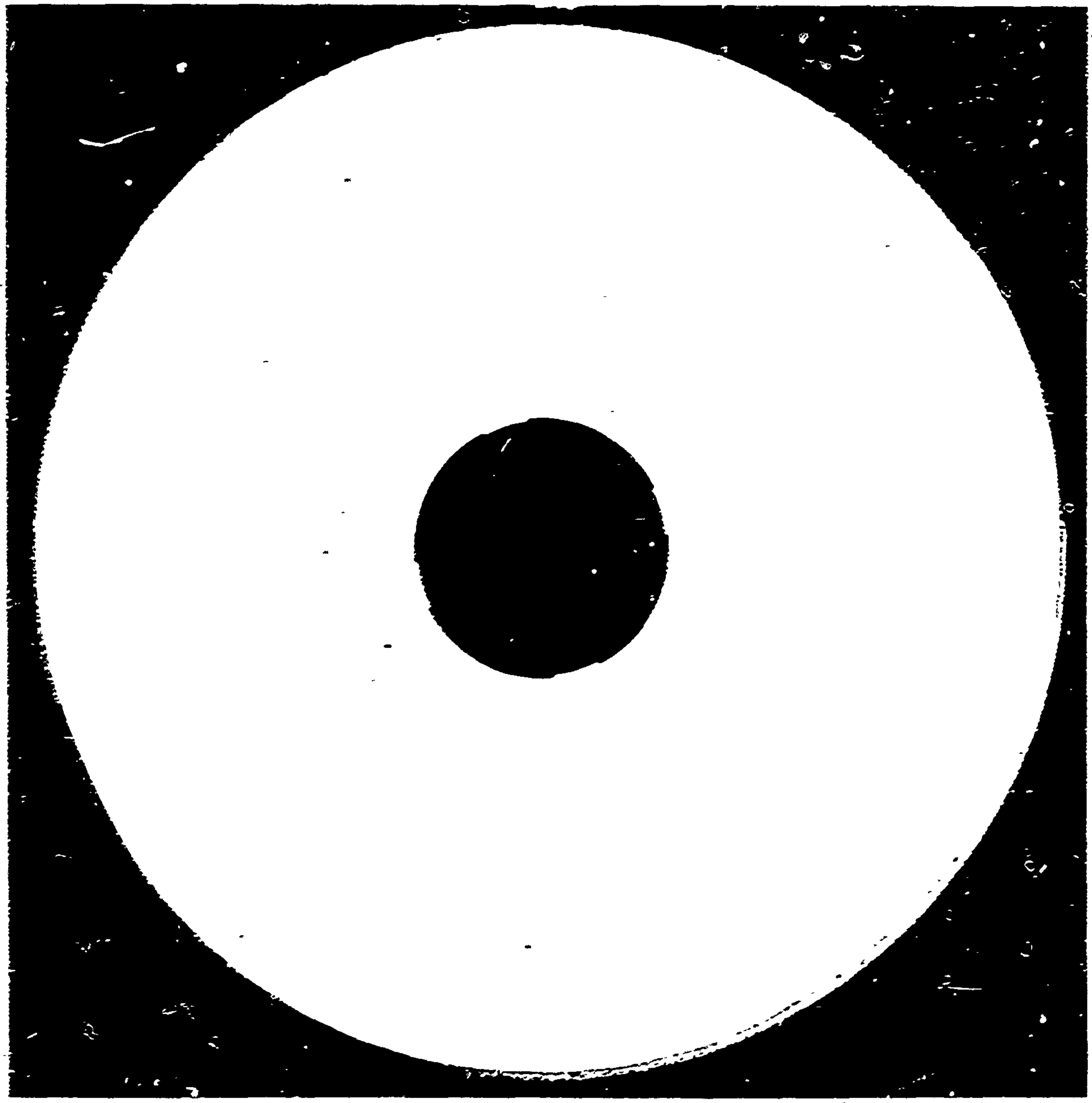
Bore Dimensions

The bore of the same metallographic sample (a transverse section) of each alloy was measured in the as-swaged condition and after heat treatment. A Tukon hardness tester with a stage and filar eyepiece was used for determining the bore dimensions to the nearest 0.0001 cm. These measurements were converted to inches.

The data in Table IX show that the bore dimensions of the gun barrel blank samples before and after heat treatment are within (or no more than 0 0003 inch over) those allowable by Rock Island Arsenal Drawing 11701204, which specifies 0.300 + 0.0015 inch and 0 308 + 0.0015 inch for the diameters between the lands and grooves, respectively. The heat treatment caused the bore dimensions of the alloys to decrease from 0 0007 to 0.0016 inch

The roundness of all the as-swaged bla- -
was very good, as may be seen from the data in Table IX. Heat treatment improved the roundness of Udimet 700, while it decreased very slightly the roundness of Inconel 718 and Crucible CG-27

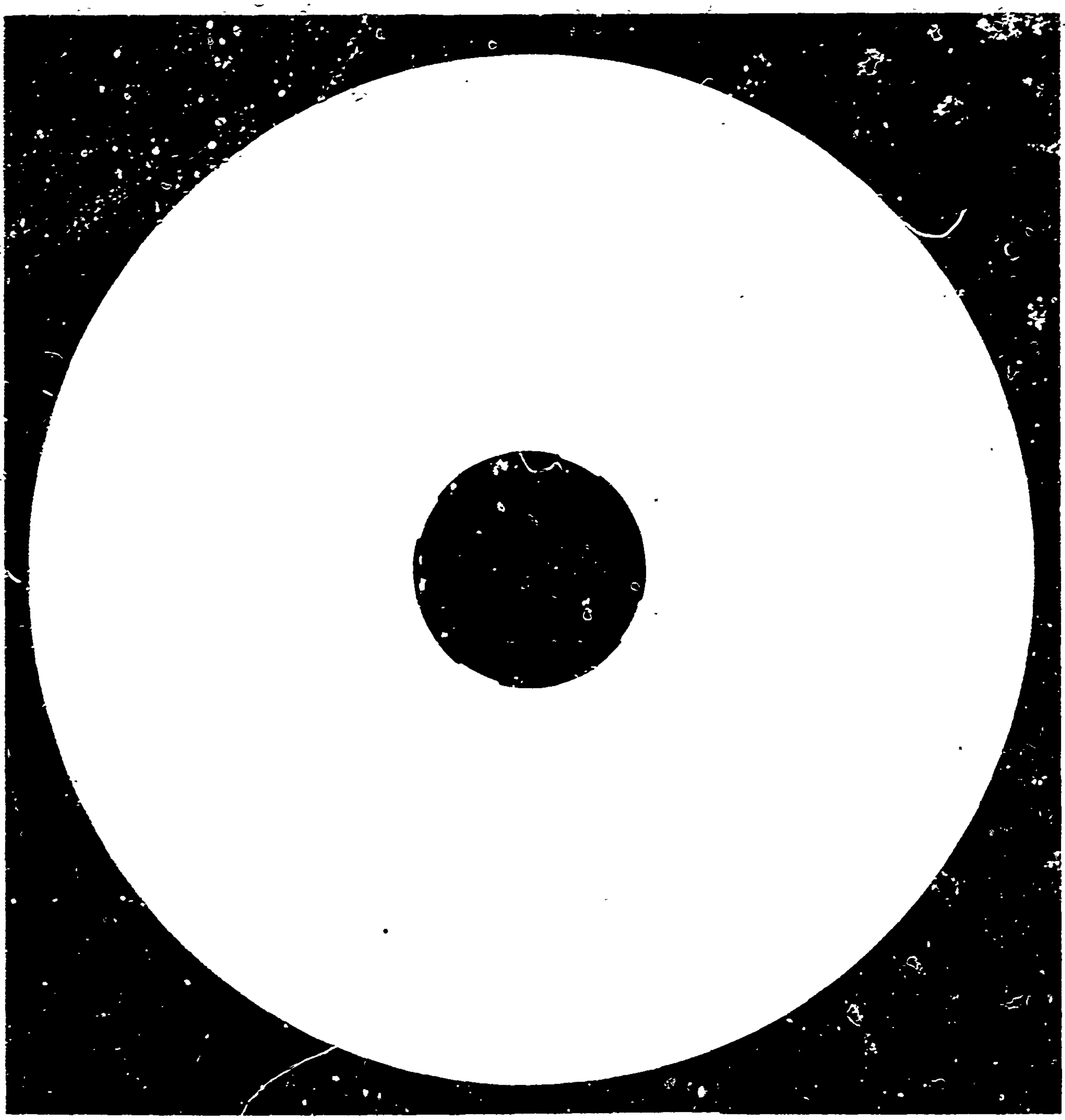
Apparently, gun barrel blanks of the age-hardenable alloys can be heat treated without destroying the bore dimensions.



5X 20 Glycerine-20 HCL-10 HNO_3 8E925

Heat Treatment: 1800 F-1-1/2 hours-air cool
1325 F-8 hours-furnace cool to 1150 F
1150 F-8 hours-air cool

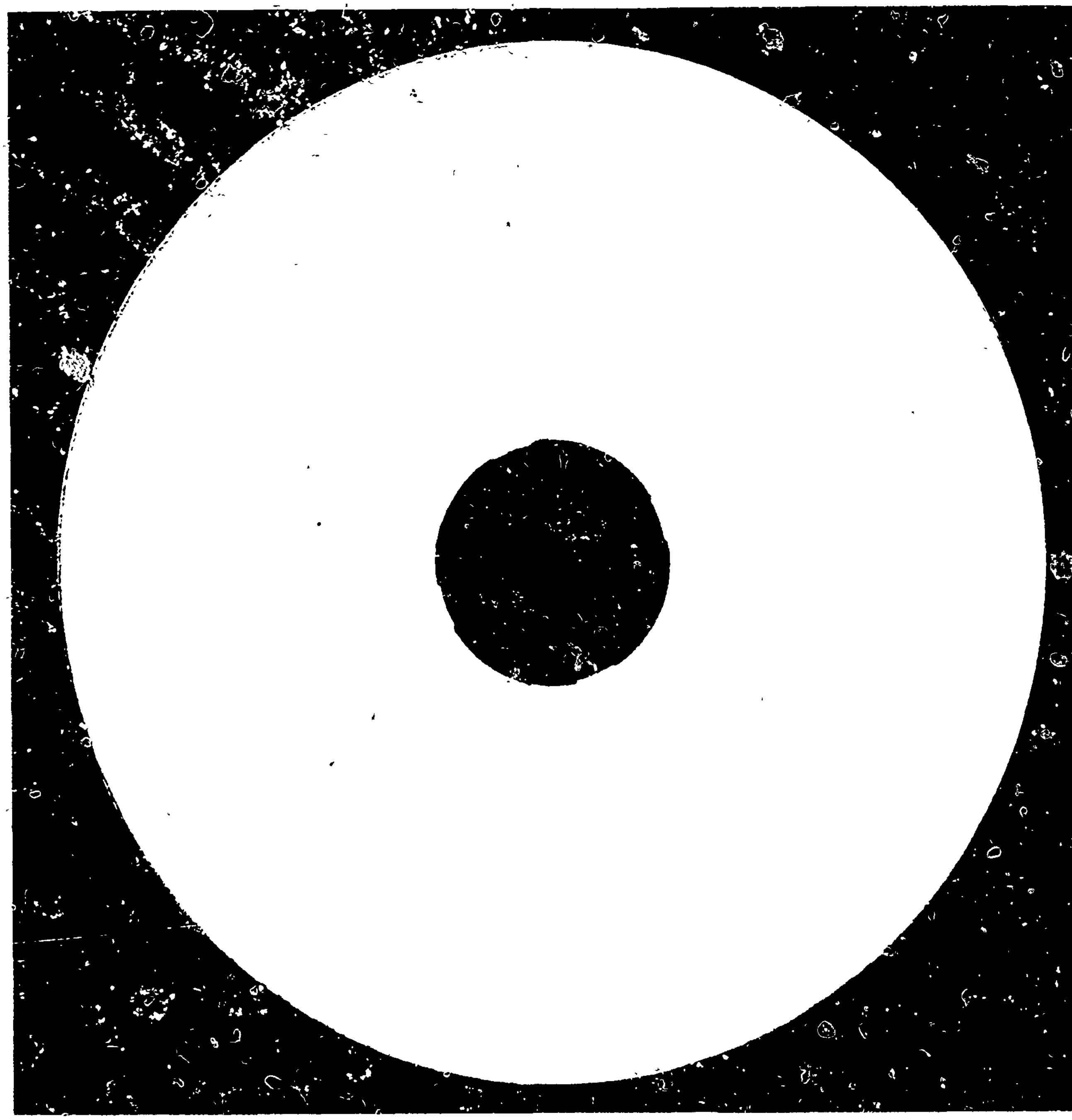
FIGURE 16 Transverse Section of Heat-Treated Inconel 718 Gun Barrel Sample 126



5X 20 Glycerine-20 HCl-10 HNO_3 8E927

Heat Treatment: 2150 F-4 hours-air cool
1975 F-4 hours-air cool
1550 F-25 hours-air cool
1440 F-16 hours-air cool

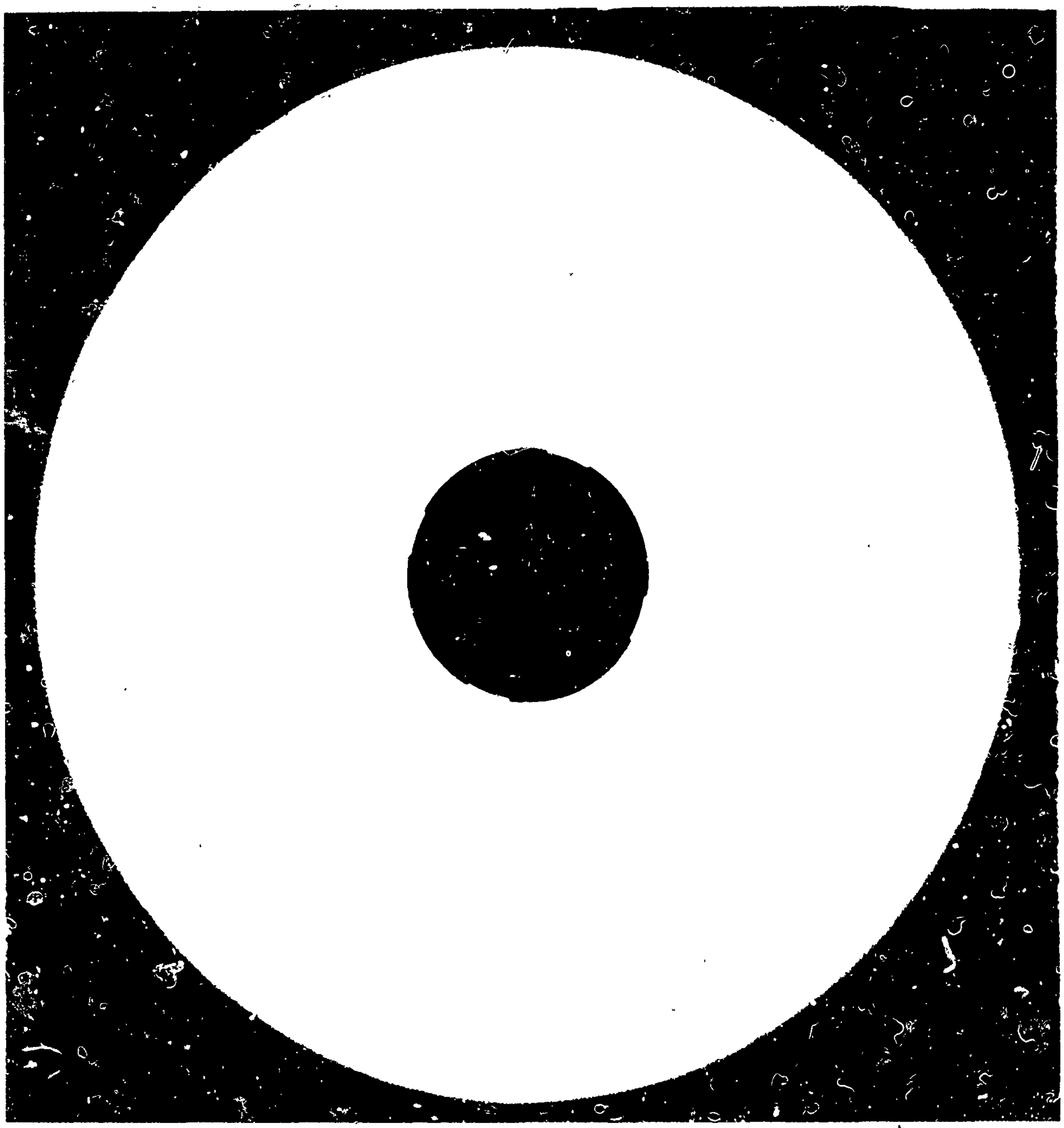
FIGURE 17 Transverse Section of Heat-Treated Udimet 700 Gun Barrel Sample 376



5X 20 Glycerine-20 HCl-10 HNO_3 8E928

Heat Treatment: 1875 F-1-1/2 hours-oil quench
1450 F-16 hours-air cool
1200 F-16 hours-air cool

FIGURE 18 Transverse Section of Heat-Treated Crucible CG-27 Gun Barrel Sample 452



5X 40 $HCl-10\ HNO_3$ 8E926

FIGURE 19 Transverse Section of As-Swaged Armco 21-6-9 Gun Barrel Sample 226

TABLE IX BORE DIMENSIONS OF GUN BARRELS

Alloy	Sample Number	As Swaged Diameter, inch		After Heat Treatment[a] Diameter, inch	
		Between Lands[b]	Between Grooves[b]	Between Lands[b]	Between Grooves[b]
Inconel 718	126	0.3016 0.3016	0.3091 0.3091	0.3000 0.3005	0.3086 0.3080
Armco 21-6-9	226	0.3007 0.3009	0.3082 0.3087	Not heat treated	
Udimet 700	376	0.3018 0.3016	0.3087 0.3091	0.3004 0.3005	0.3080 0.3080
Crucible CG-27	452	0.3018 0.3018	0.3098 0.3096	0.3014 0.3011	0.3089 0.3088

(a) Sample 126: 1800 F - 1-1/2 hr - air cooled + 1325 F - 8hr - furnace cooled to 1150 F, held at 1150 F - 8 hr - air cooled.

Sample 376: 2150 F - 4 hr - air cooled + 1975 F - 4 hr - air cooled + 1550 F - 25 hr - air cooled + 1440 F - 16 hr - air cooled.

Sample 452: 1875 F - 1-1/2 hr - oil quenched + 1450 F - 16 hr - air cooled + 1200 F - 16 hr - air cooled.

(b) Diameter measurements were made at two positions, 90 degrees apart.

Hardness Studies

Hardness determinations were made on the same transverse metallographic samples before and after heat treatment to eliminate any possible differences caused by use of different samples. Five Vickers hardness measurements were taken on the as-swaged samples along each of four radial traverses which were about 45 degrees apart. The hardness impressions were about 100 mils apart.

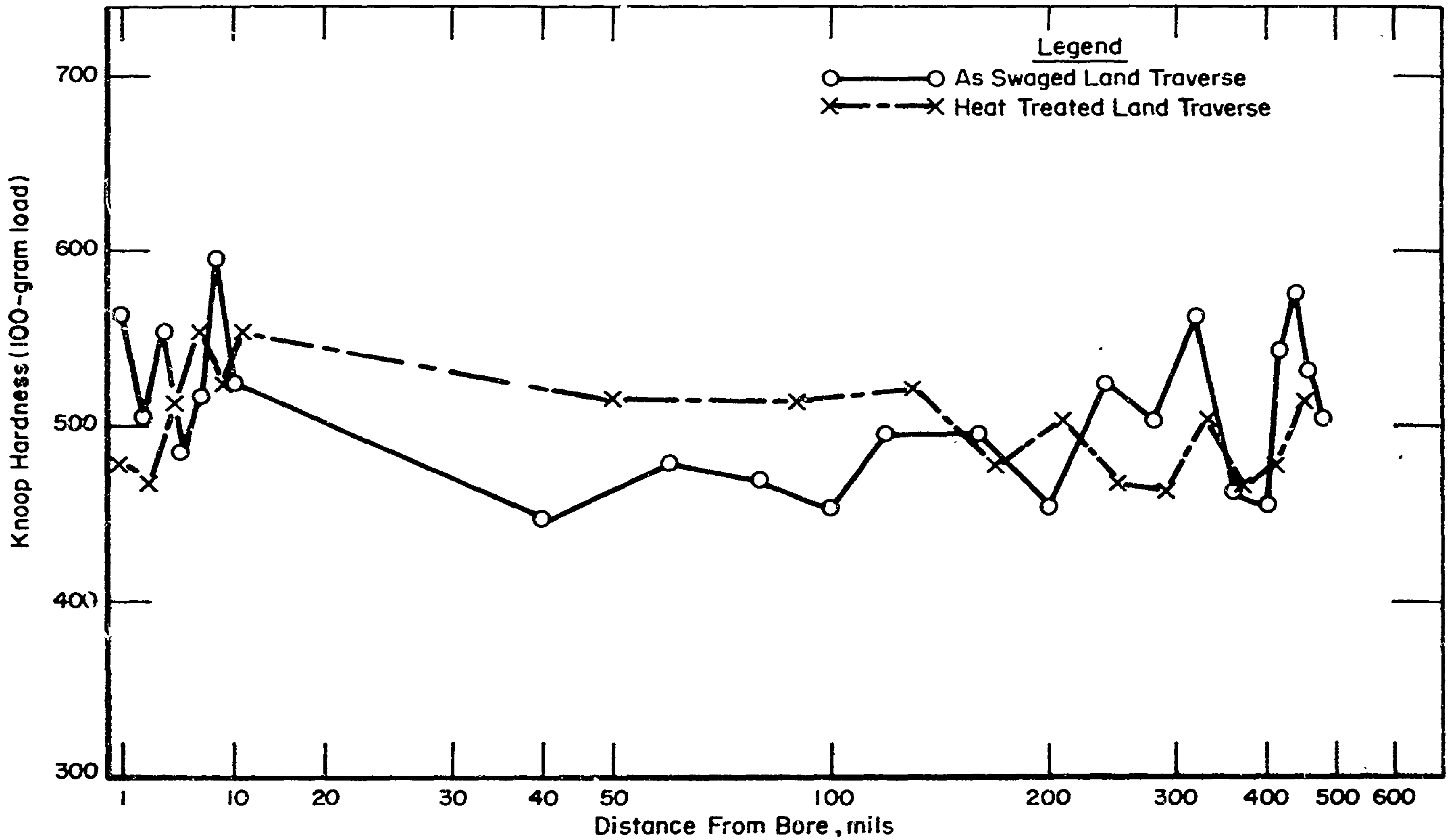
To determine hardness differences across much smaller distances required Knoop microhardness measurements of the samples in the as-swaged condition and after heat treatment. These hardness surveys were conducted along two radial traverses: one was started at a land and the other was started at a groove. In addition, circumferential traverses were made along a groove and a land approximately 1 mil from the surface of the bore.

Hardness data for the gun barrel samples before and after heat treatment are presented in Tables X and XI, and in Figures 20 through 23. A log scale was used for plotting the distance in the figures to show the complete traverse, while the first six readings close to the bore were clearly depicting.

The Vickers hardness data in Table X show that the hardnesses of all gun barrel blank samples were very high. A comparison of the data in Table IV on the gun barrel blanks with the data in Table X for the as-swaged samples shows that swaging increased the average hardness 72 VHN points for Inconel 718, 97 points for Armco 21-6-9, 124 points for Udimet 700, and 106 points for Crucible CG-27. Furthermore, the data indicate that the hardnesses of all alloys tend to be lower near the bore and to become progressively higher toward the OD.

Knoop hardness data in Table XI and in Figures 20 through 23 show that the average hardnesses of the as-swaged blank samples were very high. The hardnesses were as follows:

Alloy	Average Knoop Microhardness, 100 g. Load
Inconel 718	498
Armco 21-6-9	378
Udimet 700	629
Crucible CG-27	554



Heat Treatment: 1800 F - 1-1/2 hr - air cool + 1325 F - 8 hr,
furnace cool to 1150 F, 1150 F - 8 hr - air cool.

FIGURE 20 Knoop Hardness of Inconel 718 Gun Barrel Sample 126

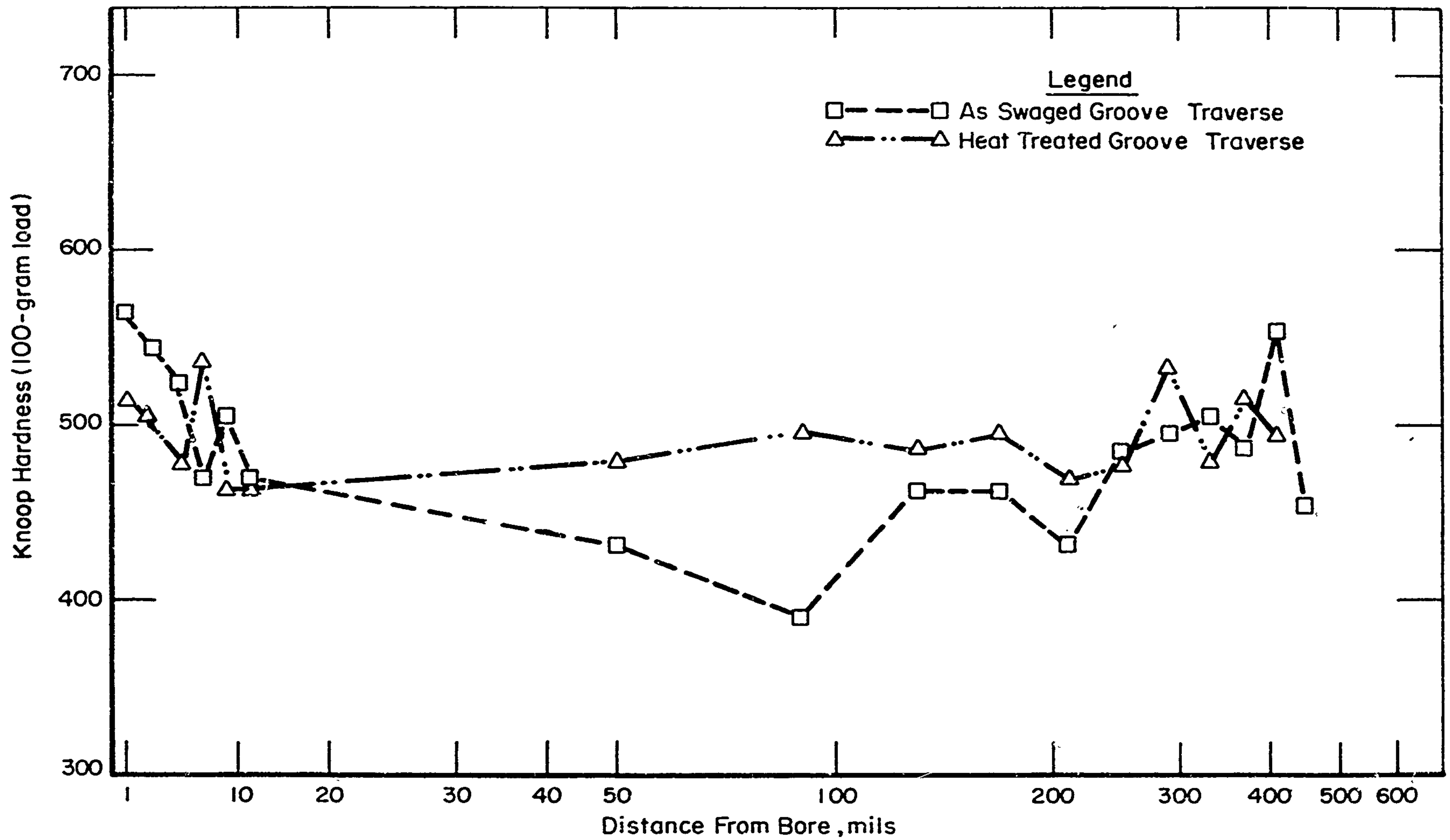


FIGURE 20 (Continued)

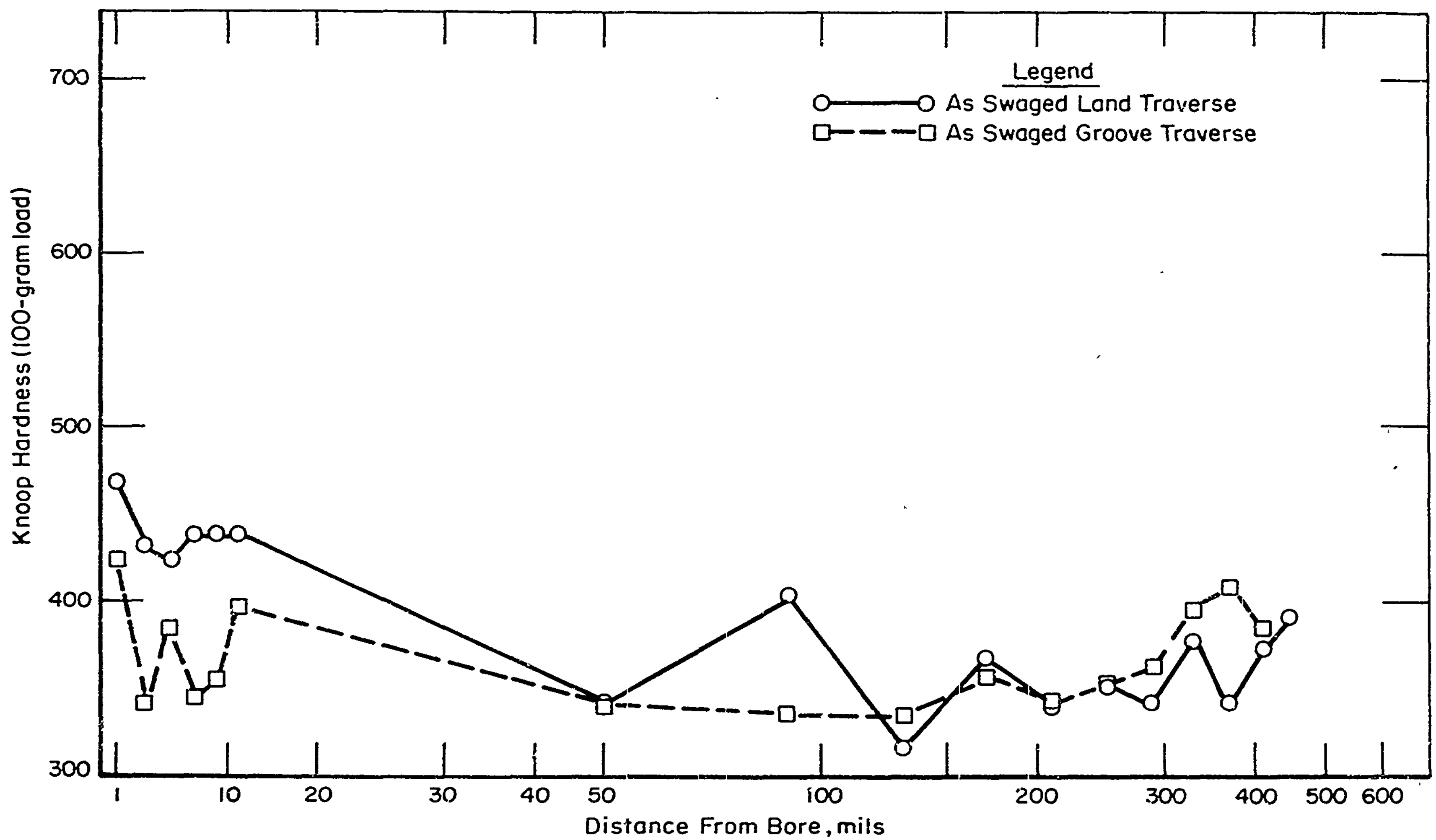
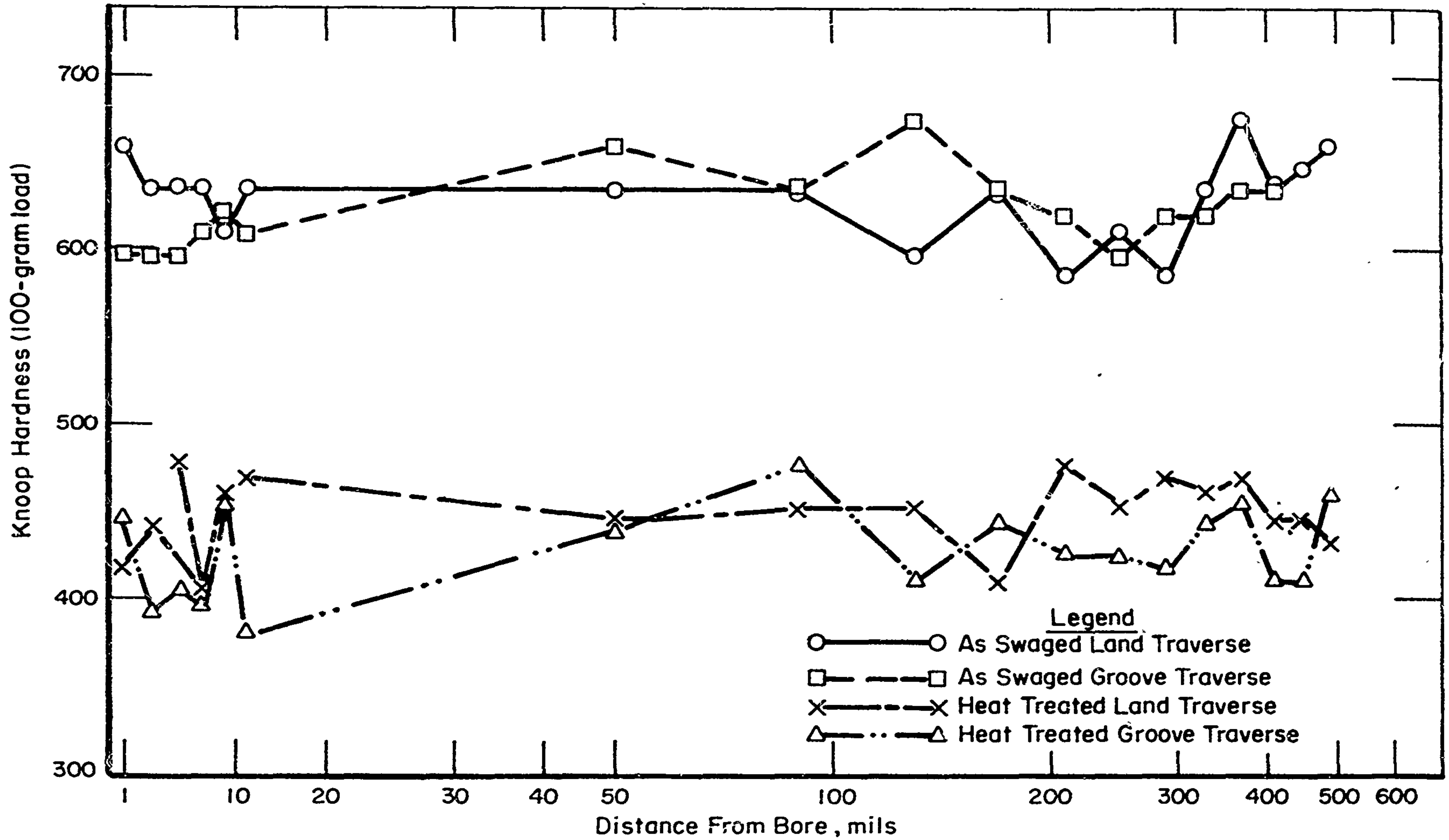
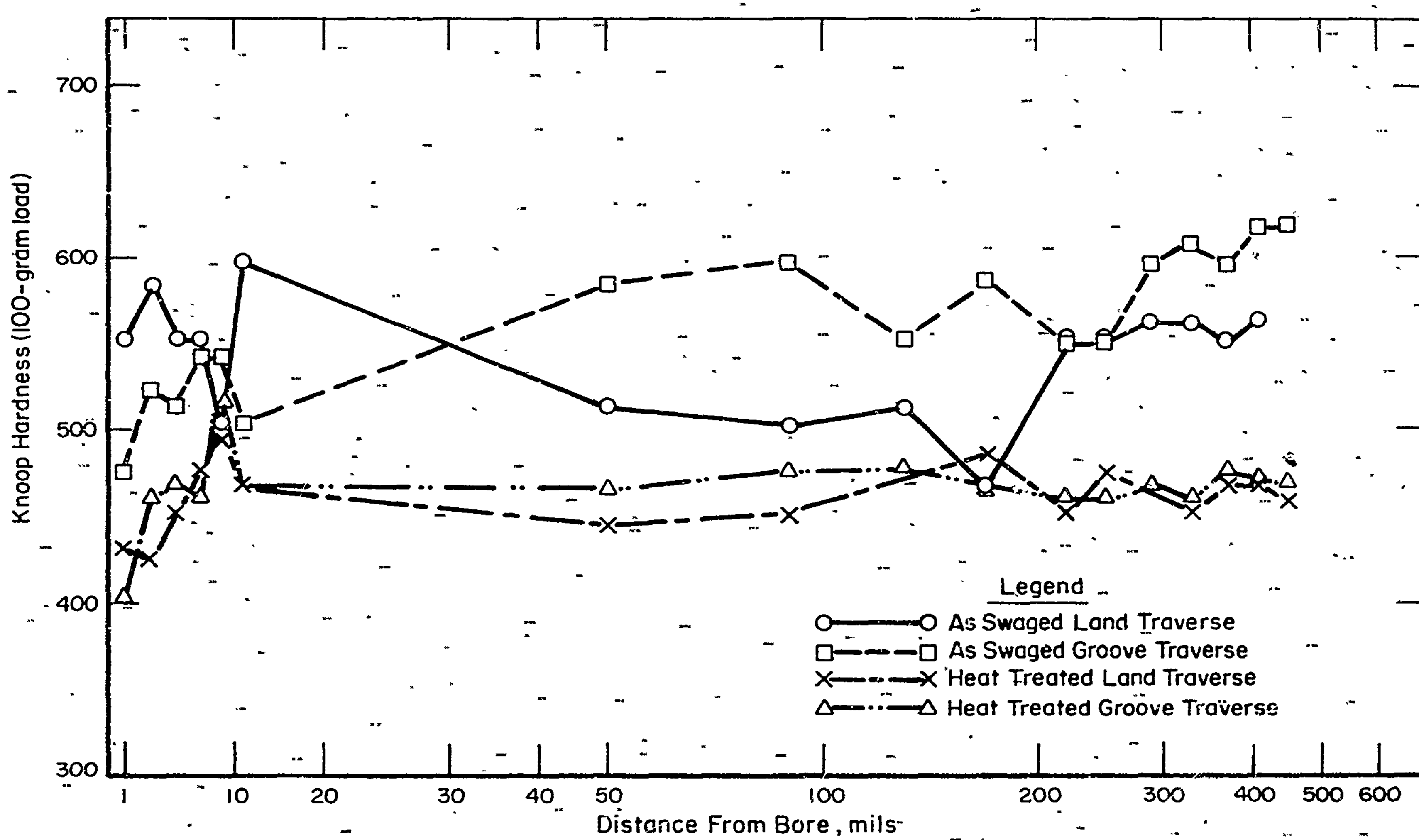


FIGURE 21 Knoop Hardness of Armco 21-6-9 Gun Barrel Sample 226



Heat Treatment: 2150 F - 4 hr - air cool + 1975 F - 4 hr - air cool +
1550 F - 25 hr - air cool + 1440 F - 16 hr - air cool.

FIGURE 22 Knoop Hardness of Udimet 700 Gun Barrel Sample 376



Heat Treatment: 1875 F - 1-1/2 hr - oil quench + 1450 F - 16 hr - air cool + 1200 F - 16 hr - air cool.

FIGURE 23 Knoop Hardness of Crucible CG-27 Gun Barrel Sample 452

TABLE X VICKERS HARDNESS OF TRANSVERSE SECTIONS OF AS-SWAGED GUN BARRELS

Alloy[a]	Location[b] of Hardness Impressions	Hardness, VHN (10-kg Load): Distance From ID, mils: 85	185	285	385	435	Average[c]	Overall: Range	Overall: Average[c]
Inconel Alloy 718 (126)	1	357	366	376	380	390	374 (39)	330-390	364 (38)
	2	360	357	360	380	383	368 (39)		
	3	357	357	387	380	373	370 (39)		
	4	336	330	363	345	345	344 (36)		
Armco Alloy 21-6-9 (226)	1	312	299	327	336	339	323 (34)	281-339	306 (32)
	2	283	281	283	294	297	287 (29)		
	3	283	294	304	333	322	307 (32)		
	4	296	283	314	317	325	307 (32)		
Udimet 700 (376)	1	498	483	525	548	548	520 (50.5)	483-572	529 (51)
	2	536	536	554	566	548	548 (52)		
	3	514	514	514	530	536	521 (50.5)		
	4	493	498	525	548	572	527 (51)		
Crucible Alloy CG-27 (452)	1	450	429	450	442	-	442 (45)	417-493	448 (46)
	2	464	459	468	478	464	467 (47)		
	3	437	442	455	429	493	451 (46)		
	4	425	417	437	428	455	432 (44)		

(a) Sample number in parenthesis.

(b) The hardness impressions were taken along four radial traverses which were about 45 degrees apart.

(c) Numbers in parentheses are Rockwell C hardness numbers converted from the Vickers numbers. The Rockwell C hardness numbers are for reference only, since the accuracy of the conversion is not known.

TABLE XI SUMMARY OF KNOOP MICROHARDNESS DATA ON GUN BARREL SAMPLES IN THE AS-SWAGED CONDITION AND AFTER HEAT TREATMENT

		Knoop Microhardness, 100g Load					
	Sample	Land Traverse		Groove Traverse		Overall	
Alloy	Number	Range	Average	Range	Average	Range	Average
As Swaged							
Inconel 718	126	446-596	508	392-563	484	392-598	498
Armco 21-6-9	226	317-470	388	336-425	367	317-470	378
Udimet 700	376	586-675	630	597-675	624	586-688	629
Crucible CG-27	452	470-597	544	477-620	563	440-620	554
Heat Treated							
Inconel 718	126	.63-554	501	469-533	492	462-565	496
Armco 21-6-9	226	-	-	-	-	-	-
Udimet 700	376	400-470	450	392-478	428	380-478	438
Crucible CG-27	452	425-495	461	404-514	467	374-514	464

Furthermore, data show that the average Knoop microhardness of Inconel 718, Udimet 700, and Crucible CG-27 decreased rather than increased after heat treatment. Udimet 700 decreased 191 points, while that of Crucible CG-27 decreased 90 points.

The hardness curves for Inconel 718 and for Udimet 700 shown in Figures 20 and 22 indicate that no significant trend occurred in hardness across land and groove traverses of the samples in the as-swaged condition and after heat treatment.

The curve in Figure 23 for Crucible CG-27 indicates that the hardness of the sample in the as-swaged and in the heat-treated condition is lowest near the bore and becomes progressively higher toward the OD.

The curve in Figure 21 for Armco 21-6-9 indicates that the hardness of the as-swaged sample is highest near the bore and becomes progressively lower toward the OD.

Fifteen high-quality experimental 7.62mm gun barrel blanks of the four alloys were selected for evaluation. The gun barrels selected according to number, alloy, and rated quality are identified in Table XII. As mentioned previously, the quality was based on straightness and on borescopic examination.

Good rifling starts approximately 3/4 inch from the swaged end and approximately 1-1/4 inches from the unswaged end of each gun barrel blank. However, these distances are approximate and must be measured on each blank.

Test Firing and Analysis of Rotary-Swaged Barrels

As part of a comprehensive program, 7.62mm gun barrels were made of Crucible CG-27 alloy by drilling and cold swaging, and by pierce-extruding and cold swaging. Barrels of both M60 and M134 configurations were test-fired in the unplated and chrome-plated conditions. Barrels were also made of fine-grained CG-27 produced by thermomechanical treatment and by powder metallurgy techniques. The results of this intensive investigation giving details of fabrication and the evaluation of material and service performance will be presented in a separate report.

TABLE XII. IDENTIFICATION AND QUALITY RATING OF EXPERIMENTAL 7.62MM GUN BARREL BLANKS

Gun Barrel	Alloy	Quality Rating[a]
11	Inconel 718	4
13	Inconel 718	2
14	Inconel 718	3
15	Inconel 718	1
21	Armco 21-6-9	1
23	Armco 21-6-9	3
24	Armco 21-6-9	4
25	Armco 21-6-9	2
31	Udimet 700	3
32	Udimet 700	5
34	Udimet 700	2
35	Udimet 700	4
38	Udimet 700	1
44	Crucible CG-27	1
45	Crucible CG-27	2

(a) A rating of (1) indicates the blank with the highest quality for the particular alloy.

The cold swaged barrel blanks of the selected nickel-base alloys were completely heat treated to develop optimum mechanical properties. These superalloys, Inconel 718 and Udimet 700, together with swaged blanks of the iron-base alloy, Armco 21-6-9, were then finish-machined to the drawing requirements of the M60 machine gun barrel. The barrels of these alloys were subjected to severe test-firing schedules and then metallurgically examined.

Typical solution treatments and aging cycles were applied to these alloys. Swaged blanks of Inconel 718 were solution-treated and aged. After each heat treatment, the blanks were cooled to room temperature, in the furnace, by influent helium.

Solution treatment - 1 hour at 1800°F.

Aging treatment - 8 hours at 1325°F, furnace cooled approximately 100°F/hour to 1150°F, held 8 hours at 1150°F.

Swaged blanks of Udimet 700 were solution-treated, stabilized, and double aged. These barrel blanks were also cooled by helium after each heat treatment.

Solution treatment - 4 hours at 2150°F.

Stabilization treatment - 4 hours at 1975°F.

Aging treatments - 25 hours at 1550°F, and 16 hours at 1440°F.

After the complete heat treatments, no distortion was observed in the bore along the length of the blanks, even though the swaged tubes were horizontally positioned in the heat-treat furnace. Chemical analysis before and after heat treatment indicates no loss of alloying elements in the materials.

The barrel blanks of the nonheat-treated Armco 21-6-9 alloy and the heat-treated nickel-base alloys were finish-machined to the drawing requirements of the M60 gun barrel, Rock Island Arsenal Drawing 140241.

The completed gun barrels of the Armco 21-6-9, Inconel 718, and Udimet 700 alloys were subjected to the following test-firing schedule:

Fire six 125-round bursts with 10-second cooling between bursts; air cool to room temperature. Continue this schedule until the barrel exceeds velocity, accuracy or yaw limits, or is otherwise considered unserviceable.

Check for velocity, accuracy, and yaw at the start of the program, after the first 3000 rounds, and after every 750 rounds.

Test-firing results obtained from this schedule are given in Table XIII.

TABLE XIII. 7.62MM M60 BARREL LIFE - FIRING SCHEDULE I

Test Barrel Material	Total Rounds Fired	Limits Exceeded
Armco 21-6-9	6000	Accuracy and yaw
Inconel 718	8600	Yaw
Udimet 700	9800	Yaw

The following more severe firing schedule was imposed on additional swaged and heat-treated gun barrels of Inconel 718 and Udimet 700:

Fire four 300-round bursts with 10-second cooling between bursts; air cool to room temperature. Continue this schedule until the barrel exceeds velocity, accuracy or yaw limits, or is unserviceable.

Check for velocity, accuracy, and yaw at the start of the program and after every 1200 rounds.

The test firing results are given in Table XIV.

TABLE XIV. 7.62MM M60 BARREL LIFE - FIRING SCHEDULE II

Test Barrel Material	Total Rounds Fired	Limits Exceeded
Inconel 718	3600	Accuracy and yaw
Udimet 700	5000	Accuracy and yaw

Sufficient heat was generated during each burst of the test-firing schedule to produce a dull red glow along the entire length of the barrel surface.

On the bore surface of the test-fired Armco 21-6-9 alloy barrel, extensive deterioration of the rifling and intergranular cracking along the entire rifle length can be observed A view of the bore near the chamber end of the barrel is given in Figure 24. Microscopic examination of sections of the bore reveals complete elimination of the lands, sharp intergranular cracks extending approximately 0 005 to 0.010-inch beneath the bore surface, and erosion by grain removal. Cracking and erosion of the bore near the origin of rifling are shown in Figure 25.

Bore replicas of each test-fired nickel-base alloy barrel reveal appreciable deterioration of the rifling, originating about 6 to 8 inches from the chamber end and extending to the muzzle end. A comparison can be made of the rifling near the chamber and muzzle ends of the bore from the replicas shown in Figures 26 and 27.

Examination of the test-fired Inconel 718 alloy barrels near the origin of rifling reveals blunt, intergranular, radial cracks originating along land-groove junctions and across land surfaces. This erosive condition of the land near the chamber end of the bore is shown in Figure 28 Three of the four lands near the muzzle end of each barrel are completely eroded The fourth land, Figures 29 and 30, has retained the rifling contour on its lead side where much friction is produced by contact with advancing projectiles

Long, sharp, intergranular cracks occurred at the bore surface near the origin of rifling of the test-fired Udimet 700 alloy barrels Similar to Inconel 718 alloy barrels, these cracks start in land-groove junctions and grain boundaries across the land surface. Land projection on the lead side and long cracks, which have become transgranular as they penetrate further beneath the bore surface, are shown in Figures 31 and 32. Near the muzzle end in the bore of the barrel test fired in Schedule I, a smooth even wear occurred which is shown in Figure 33 along with the lead side of the single remaining land. In contrast, the severe erosion by grain removal in the same area of the Schedule II barrel is illustrated in Figure 34. All lands have been completely eliminated

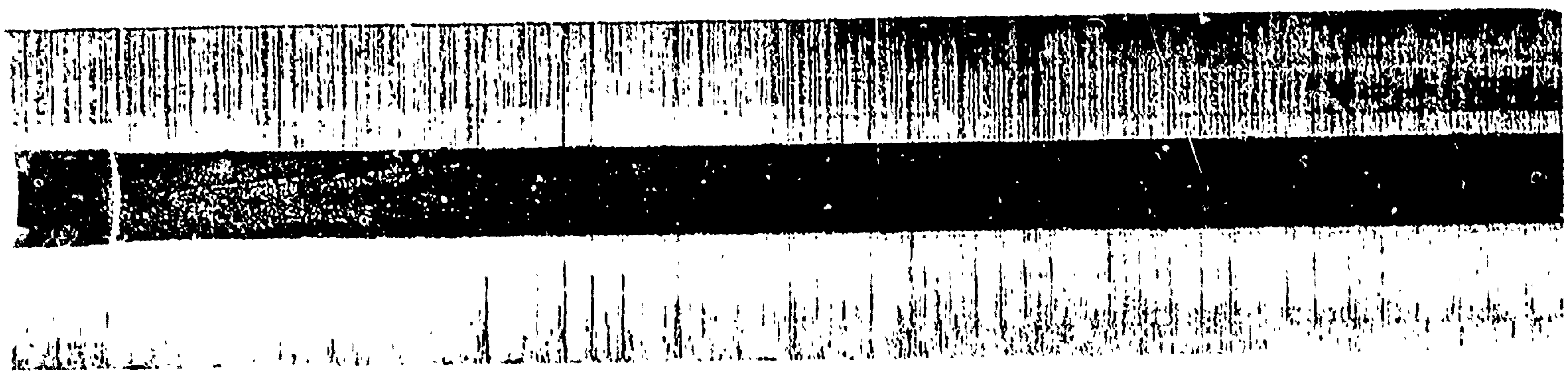
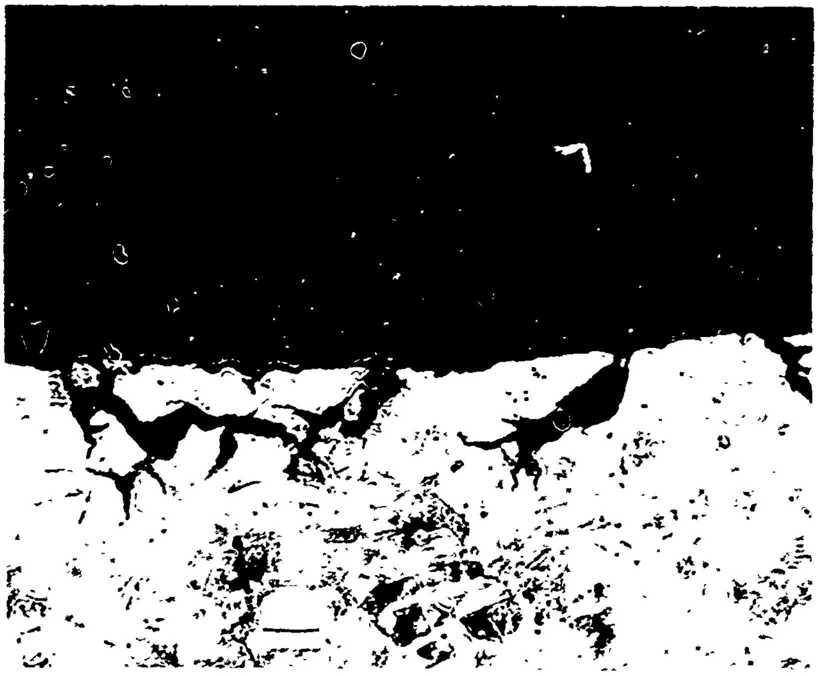


FIGURE 24 Longitudinal Section of Bore Near Chamber End of 21-6-9 Alloy M60 Gun Barrel after 6000 Rounds Schedule I.



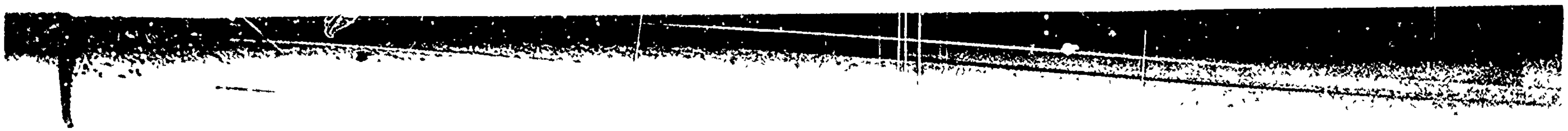
100X

FIGURE 25 Transverse Section of Bore, 1/2 Inch From Chamber, of the 21-6-9 Alloy M60 Gun Barrel after 6000 Rounds Schedule I.

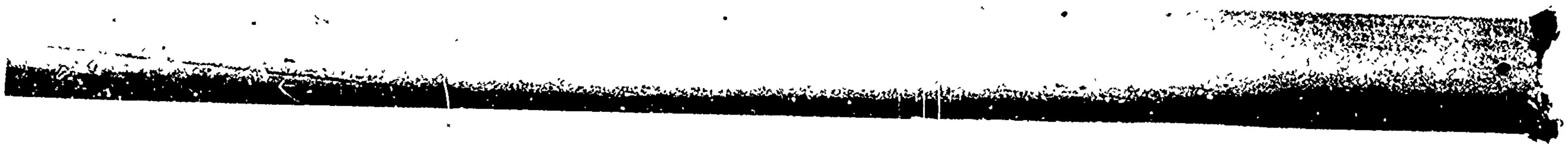
(a) Chamber End

(b) Muzzle End

FIGURE 26 Replicate of Bore of Test-Fired Inconel 718 Alloy M60 Gun Barrel after 8600 Rounds Schedule I.

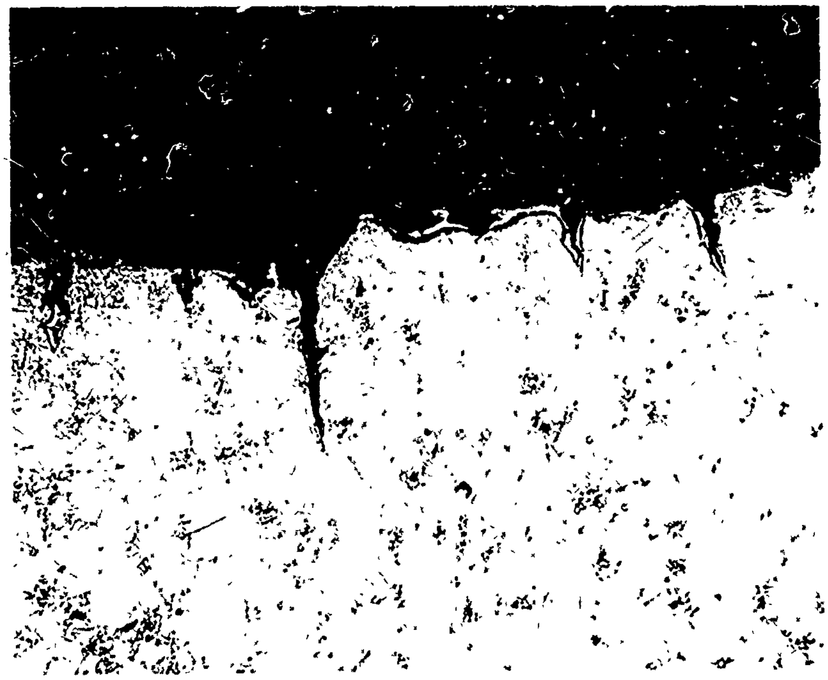


(a) Chamber End



(b) Muzzle End

FIGURE 27 Replicate of Bore of Test-Fired Udimet 700 Alloy M60 Gun Barrel after 9800 Rounds Schedule I.



100X

FIGURE 28 Transverse Section of Bore, 2 Inches From Chamber, of Inconel 718 Alloy M60 Gun Barrel after 8600 Rounds Schedule I.

100X

FIGURE 29 Transverse Section of Bore,
1 Inch From Muzzle End, of
Inconel 718 Alloy M60 Gun Barrel after 8600 Rounds
S-hedule I.

100X

FIGURE 30 Transverse Section of Bore,
1 Inch From Muzzle End, of
Inconel 718 Alloy M60 Gun Barrel after 3600 Rounds
Schedule II.

100X

FIGURE 31 Transverse Section of Bore,
2 Inches From Chamber, of
Udimet 700 Alloy M60 Gun Barrel after 980C Rounds
Schedule I

400X

FIGURE 32 Transverse Section of Bore, 1-1/2 Inches From Chamber, of Udimet 700 Alloy M60 Gun Barrel after 9800 Rounds Schedule I

400X

FIGURE 33 Transverse Section of Bore,
1 Inch From Muzzle End, of
Udimet 700 Alloy M60 Gun Barrel after 9800 Rounds
Schedule I.

400X

FIGURE 34 Transverse Section of Bore,
1 Inch From Muzzle End, of
Udimet 700 Alloy M60 Gun Barrel after 5000 Rounds
Schedule II.

Barrels made of both Inconel 718 and Udimet 700 were retired from test firing because of excessive yaw. This yaw is directly attributable to the wearing away of the lands near the muzzle end of the barrel. In spite of cracks, which form in the material, both Inconel 718 and Udimet 700 show excellent resistance to breech-end erosion. Of the two, Udimet 700 has a higher resistance to the environment imposed by rapid-fire weapons.

CONCLUSIONS

The following conclusions are based on the results of this study to produce 7.62mm rifled gun barrels from three high-temperature alloys and a stainless steel by cold swaging:

1. High-quality 7.62mm rifled gun barrel blanks of the four selected alloys - Inconel 718, Armco 21-6-9, Udimet 700, and Crucible CP-27 - can be produced by cold swaging in much shorter times than by conventional machining.

2. The recommended heat treatments for the alloys can be successfully performed on full-length as-swaged barrel blanks. Chemical analysis both before and after heat treatment indicated no loss of alloying elements.

3. The high degree of configurational integrity and the surface finish of the rifled bore are additional advantages of rotary swaging.

4. With the use of rotary-swaging techniques to produce rifling contours in tubes of high-strength materials, the use of erosion-resistant materials for rapid-fire gun barrels is feasible.

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APPENDIX A

DATA SHEETS FOR THE COLD SWAGING OF GUN BARRELS

TABLE A-1. COLD SWAGING DATA SHEETS FOR GUN BARRELS

Barrel No.:		37	38	35	34	33	21	22
Material		Udimet 700	Udimet 700	Udimet 700	Udimet 700	Udimet 700	Armco 21-6-9	Armco 21-6-9
Barrel	OD, in. Length, in.	1.330 25-1/8	1.313 26-1/8	1.312 26-1/4	1.312 26-1/4	1.312 26-5/16	1.278 27-9/16	1.307 26-5/16
Blank	OD, in. ID, in. Length, in.	1.503 20	1.503 20	1.503 20	1.502 20	1.504 20	1.500 20	1.500 20
Feed, in./min.		15	15	15	15	15	15	15
Wedges	Shim, in.	A 0.003 C 0.004	A 0.003 C 0.004	A 0.003 C 0.004	A 0.003 C 0.004	A 0.003 C 0.004	A 0.003 C 0.004	A 0.003 C 0.004
Wedge Position Dial		550	530	530	530	530	530	560
Rotation, rpm		130	130	130	130	130	130	130
Back Pressure, psi		300	400	400	400	400	400	400
Cushion Pressure, psi		800	800	800	800	800	800	800
Mandrel No.		1	1	1	1	1	1	1
Mandrel Forward Position, in.		2-5/8	2-5/8	2-5/8	2-5/8	2-5/8	2-5/8	2-5/8

TABLE A-1. (Continued)

Barrel No.:	23	24	25	15	14	11	12
Material	Armco 21-6-9	Armco 21-6-9	Armco 21-6-9	Inconel 718	Inconel 718	Inconel 718	Inconel 718
Barrel OD, in.	1.307	1.307	1.307	1.286	1.286	1.274	1.263
Barrel Length, in.	26-1/4	26-5/16	26-5/16	26-5/16	26-3/8	26-1/2	26-3/8
Blank OD, in.	1.500	1.500	1.500	1.475	1.477	1.465	1.450
Blank ID, in.							
Blank Length, in.	20	20	20	20	20	20	20
Feed, in./min.	15	15	15	15	15	15	15
Wedges Shim, in.	A 0.003 C 0.004	A 0.003 C 0.004	A 0.003 C 0.004	A 0.003 C 0.004	A 0.003 C 0.004	A 0.003 C 0.004	A 0.003 C 0.004
Wedge Position Dial	560	560	560	530	530	520	510
Rotation, rpm	130	130	130	130	130	130	130
Back Pressure, psi	400	400	40[illegible]	400	400	400	400
Cushion Pressure, psi	800	800	800	800	800	800	800
Mandrel No.	1	1	1	1	1	1	1
Mandrel Forward Position, in.	2-5/8	2-5/8	2-5/8	2-5/8	2-5/8	2-5/8	2-5/8

TABLE A-1. (Continued)

Barrel No.:		13	41	32	31	42	43	44	45
Material		Inconel 718	Crucible CG-27	Udimet 700	Udimet 700	Crucible CG-27	Crucible CG-27	Crucible CG-27	Crucible CG-27
Barrel	OD, in.	1.260	1.319	1.313	1.314	1.311	1.311	1.303	1.303
	Length, in.		26	26-3/16	26-3/16	26-3/8	26-3/8	26-5/8	26-5/8
Blank	OD, in.	1.445	1.504	1.500	1.500	1.500	1.504	1.505	1.504
	ID, in.								
	Length, in.	20	20	20	20	20	20	20	20
Feed, in./min.		15	15	15	15	15	15	12	12
Wedges	Shim, in.	A 0.003 C 0.004	A 0.003 C 0.004	A 0.004 C 0.004	A 0.004 C 0.004	A 0.004 C 0.004	A 0.004 C 0.004	A 0.008 A 0.008	A 0.008 C 0.008
Wedge Position Dial		505	550	530	530	540	540	540	540
Rotation, rpm		130	130	130	130	130	130	105	105
Back Pressure, psi		400	400	400	400	400	450	450	450
Cushion Pressure, psi		800	800	800	800	800	800	800	800
Mandrel No.		1	1	2	2	2	2	2	2
Mandrel Forward Position, in.		2-5/8	2-5/8	2-5/8	2-5/8	2-5/8	2-5/8	2-5/8	2-5/8

APPENDIX B

DIAMETER AND STRAIGHTNESS DATA
COLD-SWAGED GUN BARRELS

APPENDIX B

DIAMETER AND STRAIGHTNESS DATA COLD-SWAGED GUN BARRELS

The diameters of the swaged gun barrels were measured with a micrometer at distances of 1-1/2, 8-1/2, 15-3/8, and 22-3/8 inches from the end of the barrel. Two measurements, 90 degrees apart, were taken at the four locations to determine the degree of out-of-roundness. The diameter measurements are given in Table B-1.

The straightness of the swaged gun barrels was measured by means of a dial indicator. The gun barrels were placed in a lathe and the indicator was moved along the length of the barrel in four traverses 90 degrees apart. Readings were taken along the traverses at distances of 1-1/2, 8-1/2, 15-3/8, and 22-3/8 inches from one end of the barrel. The indicator readings are given in Tables B-2 through B-5. The first indicator reading was taken as the zero point. The total indicator reading (TIR) is given for each traverse.

TABLE B-1. DIAMETER MEASUREMENTS TAKEN ON AS-SWAGED GUN BARRELS

Alloy	Barrel Number	Diameter[a] (in inches) at Indicated Distance From End of Barrel: 1-1/2 inches A	1-1/2 inches B	8-1/2 inches A	8-1/2 inches B	15-3/8 inches A	15-3/8 inches B	22-3/8 inches A	22-3/8 inches B
Inconel 718	11	1.273	1.273	1.273	1.272	1.272	1.272	1.271	1.272
	12	1.263	1.262	1.262	1.262	1.262	1.262	1.262	1.261
	13	1.260	1.260	1.258	1.259	1.258	1.258	1.257	1.257
	14	1.286	1.286	1.286	1.286	1.285	1.285	1.284	1.285
	15	1.287	1.287	1.286	1.286	1.285	1.285	1.285	1.285
Armco 21-6-9	21	1.278	1.278	1.277	1.277	1.277	1.277	1.276	1.276
	22	1.307	1.308	1.306	1.307	1.305	1.306	1.305	1.306
	23	1.307	1.307	1.306	1.306	1.306	1.306	1.305	1.306
	24	1.307	1.307	1.306	1.306	1.305	1.306	1.305	1.305
	25	1.307	1.307	1.307	1.306	1.306	1.305	1.305	1.305
Udimet 700	31	1.315	1.315	1.314	1.314	1.313	1.313	1.312	1.312
	32	1.313	1.313	1.312	1.312	1.312	1.311	1.311	1.311
	33	1.312	1.312	1.312	1.312	1.311	1.311	1.311	1.311
	34	1.314	1.314	1.313	1.313	1.312	1.312	1.311	1.311
	35	1.313	1.313	1.313	1.313	1.312	1.312	1.311	1.312
	37	1.331	1.330	1.331	1.331	1.330	1.331	1.330	1.331
	38	1.314	1.314	1.313	1.314	1.313	1.313	1.312	1.312
Crucible CG-27	41	1.320	1.320	1.319	1.319	1.319	1.319	1.316	1.316
	42	1.310	1.310	1.310	1.310	1.310	1.310	1.311	1.311
	43	1.309	1.309	1.309	1.309	1.309	1.309	1.310	1.310
	44	1.307	1.307	1.305	1.305	1.302	1.303	1.301	1.301
	45	1.303	1.303	1.303	1.303	1.303	1.303	1.303	1.304

(a) Positions A and B were 90 degrees apart.

TABLE B-2. STRAIGHTNESS MEASUREMENTS TAKEN ON AS-SWAGED 718 GUN BARRELS

Gun Barrel Number	Traverse Number(a)	Dial Indicator Reading (inch) at Indicated Distance From End of Barrel				Total Indicator Reading(b) (T.I.R.), in.
		1-1/2 in.	8-1/2 in.	15-3/8 in.	22-3/8 in.	
11	1	0.000	+0.007	+0.012	+0.005	0.012
	2	+0.001	0.000	-0.001	-0.004	0.005
	3	-0.005	-0.013	-0.018	-0.013	0.013
	4	-0.007	-0.004	-0.005	-0.005	0.003
12	1	0.000	+0.010	+0.010	+0.002	0.010
	2	+0.003	+0.018	+0.018	+0.010	0.015
	3	+0.004	-0.015	-0.022	-0.020	0.026
	4	-0.007	-0.022	-0.027	-0.025	0.020
13	1	0.000	+0.0005	+0.0015	0.000	0.0015
	2	0.000	-0.006	-0.009	-0.0075	0.009
	3	-0.004	-0.0065	-0.011	-0.011	0.007
	4	-0.004	+0.002	+0.0005	-0.003	0.006
14	1	0.000	+0.0025	-0.001	-0.002	0.0045
	2	-0.006	-0.018	-0.018	-0.011	0.012
	3	-0.007	-0.009	-0.007	-0.007	0.002
	4	-0.001	+0.010	+0.009	+0.0015	0.011
15	1	0.000	-0.002	-0.003	-0.001	0.003
	2	-0.001	+0.002	+0.0025	+0.0017	0.0035
	3	-0.002	0.000	-0.002	-0.0045	0.0045
	4	-0.001	-0.0045	-0.007	-0.007	0.006

(a) Traverses were 90 degrees apart along the length of the barrel.

(b) The value given is the difference between the maximum and minimum indicator readings along a given traverse.

TABLE B-3. STRAIGHTNESS MEASUREMENTS TAKEN ON AS-SWAGED ARMCO ALLOY 21-6-9 GUN BARRELS

Gun Barrel Number	Traverse Number(a)	Dial Indicator Reading (inch) at Indicated Distance From End of Barrel: 1-1/2 in.	8-1/2 in.	15-3/8 in.	22-3/8 in.	Total Indicator Reading(b) (T.I.R.), in.
21	1	0.000	-0.003	-0.007	-0.007	0.007
	2	-0.0015	-0.006	-0.007	-0.004	0.0055
	3	-0.0005	+0.003	+0.004	+0.002	0.0045
	4	+0.002	+0.005	+0.004	0.000	0.005
22	1	0.000	-0.0025	-0.006	-0.004	0.006
	2	+0.0005	+0.001	+0.001	+0.0025	0.002
	3	+0.0002	+0.003	+0.004	+0.001	0.0038
	4	0.000	-0.001	-0.004	-0.006	0.006
23	1	0.000	-0.0005	0.000	0.000	0.0005
	2	+0.0005	+0.0025	+0.0015	-0.0015	0.004
	3	0.000	-0.001	-0.004	-0.005	0.005
	4	-0.001	-0.004	-0.0055	-0.004	0.0045
24	1	0.000	-0.002	-0.0042	-0.004	0.0042
	2	-0.001	-0.0025	-0.0035	-0.002	0.0025
	3	-0.0015	-0.001	-0.002	-0.0035	0.0025
	4	-0.001	0.000	-0.0022	-0.0055	0.0055
25	1	0.000	-0.002	-0.006	-0.006	0.006
	2	-0.0005	+0.001	-0.001	-0.003	0.004
	3	-0.00015	0.000	+0.001	0.000	0.00115
	4	-0.001	-0.003	-0.004	-0.003	0.003

(a) Traverses were 90 degrees apart along the length of the barrel.

(b) The value given is the difference between the maximum and minimum indicator readings along a given traverse.

TABLE B-3. STRAIGHTNESS MEASUREMENTS TAKEN ON AS-SWAGED ARMCO ALLOY 21-6-9 GUN BARRELS

Gun Barrel Number	Traverse Number(a)	Dial Indicator Reading (inch) at Indicated Distance From End of Barrel: 1-1/2 in.	8-1/2 in.	15-3/8 in.	22-3/8 in.	Total Indicator Reading(b) (T.I.R.), in.
21	1	0.000	-0.003	-0.007	-0.007	0.007
	2	-0.0015	-0.006	-0.007	-0.004	0.0055
	3	-0.0005	+0.003	+0.004	+0.002	0.0045
	4	+0.002	+0.005	+0.004	0.000	0.005
22	1	0.000	-0.0025	-0.006	-0.004	0.006
	2	+0.0005	+0.001	+0.001	+0.0025	0.002
	3	+0.0002	+0.003	+0.004	+0.001	0.0038
	4	0.000	-0.001	-0.004	-0.006	0.006
23	1	0.000	-0.0005	0.000	0.000	0.0005
	2	+0.0005	+0.0025	+0.0015	-0.0015	0.004
	3	0.000	-0.001	-0.004	-0.005	0.005
	4	-0.001	-0.004	-0.0055	-0.004	0.0045
24	1	0.000	-0.002	-0.0042	-0.004	0.0042
	2	-0.001	-0.0025	-0.0035	-0.002	0.0025
	3	-0.0015	-0.001	-0.002	-0.0035	0.0025
	4	-0.001	0.000	-0.0022	-0.0055	0.0055
25	1	0.000	-0.002	-0.006	-0.006	0.006
	2	-0.0005	+0.001	-0.001	-0.003	0.004
	3	-0.00015	0.000	+0.001	0.000	0.00115
	4	-0.001	-0.003	-0.004	-0.003	0.003

(a) Traverses were 90 degrees apart along the length of the barrel.

(b) The value given is the difference between the maximum and minimum indicator readings along a given traverse.

TABLE B-4. STRAIGHTNESS MEASUREMENTS TAKEN ON AS-SWAGED UDIMET 700 GUN BARRELS

Gun Barrel Number	Traverse Number(a)	Dial Indicator Reading (inch) at Indicated Distance From End of Barrel				Total Indicator Reading(b) (T.I.R.), in.
		1-1/2 in.	8-1/2 in.	15-3/8 in.	22-3/8 in.	
31	1	0.000	+0.005	+0.005	+0.003	0.005
	2	+0.002	+0.003	+0.0015	0.000	0.003
	3	-0.0023	-0.0035	-0.0065	-0.006	0.0042
	4	+0.001	-0.001	-0.004	-0.004	0.005
32	1	0.000	-0.005	-0.007	-0.010	0.010
	2	-0.003	-0.0057	-0.0095	-0.009	0.0065
	3	-0.005	-0.001	-0.001	-0.0005	0.0045
	4	-0.002	0.000	+0.0015	0.000	0.002
33	1	0.000	+0.001	+0.001	+0.0004	0.001
	2	0.000	-0.001	-0.004	-0.003	0.004
	3	-0.001	-0.0028	-0.005	-0.0055	0.0045
	4	-0.001	0.000	0.000	-0.002	0.002
34	1	0.000	0005	-0.001	-0.001	0.001
	2	+0.0035	.0017	0.000	-0.0015	0.005
	3	+0.004	+0.0043	+0.003	+0.0007	0.0036
	4	+0.001	+0.0025	+0.002	+0.001	0.0015
35	1	0.000	0.000	-0.001	-0.003	0.003
	2	+0.001	+0.0005	-0.002	-0.003	0.004
	3	0.000	-0.001	-0.003	-0.001	0.003
	4	-0.0005	-0.0012	-0.001	-0.001	0.0007
37	1	0.000	+0.002	+0.004	+0.004	0.004
	2	-0.0015	+0.001	+0.001	+0.0005	0.0025
	3	-0.0007	-0.003	-0.0075	-0.008	0.0073
	4	+0.0015	-0.002	-0.005	-0.0045	0.0065

TABLE B-4. STRAIGHTNESS MEASUREMENTS TAKEN ON AS-SWAGED UDIMET 700 GUN BARRELS

Gun Barrel Number	Traverse Number[a]	Dial Indicator Reading (inch) at Indicated Distance From End of Barrel				Total Indicator Reading[b] (T.I.R.), in.
		1-1/2 in.	8-1/2 in.	15-3/8 in.	22-3/8 in.	
31	1	0.000	+0.005	+0.005	+0.003	0.005
	2	+0.002	+0.003	+0.0015	0.000	0.003
	3	-0.0023	-0.0035	-0.0065	-0.006	0.0042
	4	+0.001	-0.001	-0.004	-0.004	0.005
32	1	0.000	-0.005	-0.007	-0.010	0.010
	2	-0.003	-0.0057	-0.0095	-0.009	0.0065
	3	-0.005	-0.001	-0.001	-0.0005	0.0045
	4	-0.002	0.000	+0.0015	0.000	0.002
33	1	0.000	+0.001	+0.001	+0.0004	0.001
	2	0.000	-0.001	-0.004	-0.003	0.004
	3	-0.001	-0.0028	-0.005	-0.0055	0.0045
	4	-0.001	0.000	0.000	-0.002	0.002
34	1	0.000	0005	-0.001	-0.001	0.001
	2	+0.0035	.0017	0.000	-0.0015	0.005
	3	+0.004	+0.0043	+0.003	+0.0007	0.0036
	4	+0.001	+0.0025	+0.002	+0.001	0.0015
35	1	0.000	0.000	-0.001	-0.003	0.003
	2	+0.001	+0.0005	-0.002	-0.003	0.004
	3	0.000	-0.001	-0.003	-0.001	0.003
	4	-0.0005	-0.0012	-0.001	-0.001	0.0007
37	1	0.000	+0.002	+0.004	+0.004	0.004
	2	-0.0015	+0.001	+0.001	+0.0005	0.0025
	3	-0.0007	-0.003	-0.0075	-0.008	0.0073
	4	+0.0015	-0.002	-0.005	-0.0045	0.0065

TABLE B-4. (Continued)

Gun Barrel Number	Traverse Number[a]	Dial Indicator Reading (inch) at Indicated Distance From End of Barrel				Total Indicator Reading[b] (T.I.R.), in.
		1-1/2 in.	8-1/2 in.	15-3/8 in.	22-3/8 in.	
38	1	0.000	0.000	-0.0025	-0.003	0.003
	2	+0.0015	+0.001	-0.0004	-0.0005	0.002
	3	+0.002	+0.0015	+0.001	0.000	0.002
	4	0.000	0.000	-0.0015	-0.003	0.003

(a) Traverses were 90 degrees apart along the length of the barrel.

(b) The value given is the difference between the maximum and minimum indicator readings along a given traverse.

TABLE B-5. STRAIGHTNESS MEASUREMENTS TAKEN ON AS SWAGED CRUCIBLE ALLOY CG-27 GUN BARRELS

Gun Barrel Number	Traverse Number(a)	Dial Indicator Reading (inch) at Indicated Distance From End of Barrel				Total Indicator Reading(b) (T.I.R.), in.
		1-1/2 in.	8-1/2 in.	15-3/8 in.	22-3/8 in.	
41	1	0.000	0.000	0.000	+0.0015	0.0015
	2	-0.003	-0.0035	-0.005	-0.0065	0.0035
	3	-0.0025	-0.003	-0.006	-0.0065	0.004
	4	0.000	0.000	-0.001	-0.001	0.001
42	1	0.000	+0.001	0.000	-0.002	0.003
	2	+0.004	+0.007	+0.005	+0.005	0.003
	3	+0.0035	+0.003	+0.0025	+0.004	0.0015
	4	0.000	-0.003	-0.003	+0.002	0.005
43	1	0.000	-0.005	-0.0045	0.000	0.005
	2	-0.003	-0.001	0.000	-0.0004	0.003
	3	+0.002	+0.007	+0.004	-0.0002	0.0072
	4	+0.0045	+0.003	-0.001	+0.0003	0.0055
44	1	0.000	0.000	0.000	-0.001	0.001
	2	-0.0035	-0.008	-0.012	-0.012	0.0085
	3	-0.005	-0.008	-0.010	-0.011	0.006
	4	-0.001	+0.0005	+0.002	0.000	0.003
45	1	0.000	+0.002	+0.0005	-0.0015	0.0035
	2	+0.001	+0.0015	0.000	-0.0035	0.005
	3	-0.003	-0.006	-0.007	-0.0046	0.004
	4	-0.005	-0.005	-0.005	-0.003	0.002

(a) Traverses were 90 degrees apart along the length of the barrel.

(b) The value given is the difference between the maximum and minimum indicator readings along a given traverse.